A COURSE OF EXERCISES

IN

ELEMENTARY PHYSICS.

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PUBLISHED BY

THE BERKELEY PRESS,

Box 2122,

SAN FRANCISCO,

1894.

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*Comparatively elementary.
†Difficult of explanation.
**Suitable for Preparatory Schools.
‡Difficult on practical grounds.

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PREFACE.

This book consists in a collection of directions for some sixty or more exercises in elementary physics, which have been given during the current academic year (1893—1894) to students in the University of California. It is not expected that these directions, which were prepared under stress of work, will be free from faults or inconsistencies; but they have been found to yield, in most cases, sufficiently satisfactory results to warrant their issuance for another year; and it has been thought desirable to print them—this being, on the whole, the most economical method of distribution.

A secondary object in printing these directions has been to lay before the teachers of this State a proposed line of demarcation between High School and College work, and to invite discussion and criticism upon this subject. The exercises included in this book are not intended to represent an ideal course either in a university or in a high school; but rather a collection of exercises intermediate in grade between the work at present performed in high schools, and that aimed at in our University. The desirability of a complete understanding and accord as to the division of such work between School and College must be evident to every teacher of physics in this State.

Excellent suggestions as to the nature of a High School course in physics will be found in the report of two members of the "Committee of Ten" published by the United States Bureau of Education, 1893. At the same time,

serious faults seem to exist in this report. The introduction of "Wheatstone's bridge" (before the student has any adequate idea of the distribution of potential in an electric circuit) is certainly objectionable; as is also the study of the laws of motion at a point of time when the student can hardly be familiar with the mathematical expressions necessary to the understanding of acceleration. On the other hand, the author has shown that a determination of the "mechanical equivalent of heat" can be made by any student with considerable accuracy and at a nominal cost, as far as apparatus is concerned. Other methods of reaching the same end can doubtless be devised by any teacher having a moderate degree of ingenuity. Under the circumstances, the inclusion of this fundamental and highly instructive experiment in any extended high school course would seem to be desirable. Several other criticisms upon the course suggested by the "Committee of Ten" might be made here; but it is thought that the author's opinions on this subject are sufficiently exemplified by the list of exercises included in this book.

In the Table of Contents, exercises which contain parts suitable (in the author's opinion) for a high school course are marked with an asterisk (*), and those which might perhaps be adopted without essential modification are marked with two asterisks. Exercises, however, involving theoretical difficulties, which cannot be explained satisfactorily to beginners, are distinguished by a dagger (†); and those offering experimental obstacles, too great to be overcome in the teaching of large classes, are distinguished by a double dagger (‡).

The exercises have been found to occupy each from two to three hours of a student's time. It is hoped that the majority of those in the first half of the list which are doubly starred may eventually find a place in the best high schools, without prejudice to the simpler experiments now taught there. In order that a place may be found for them, it is suggested that certain other experiments which have been found to offer practical or theoretical difficulties

even to more advanced students should be omitted. The first half of the exercises included in this book, covering hydrostatics, heat, light, and sound, would according to this scheme fall largely to the High School, while the laws of motion, and electrical or magnetic measurements in general, would constitute a more advanced course, taught only in the University, or in schools preparing students for advanced standing.

It is not suggested that experiments in electricity and magnetism should be excluded altogether from the High School, but that the work in these branches should be confined to fundamental phenomena, and that these even should not be studied to the prejudice of other branches of physics, a thorough knowledge of which is necessary for the subsequent understanding of the phenomena in question.

Teachers who wish to introduce exercises like those here outlined into school work should arrange, if possible, to have at least two successive school hours for their laboratory sections. Each student should be assigned to a given desk (in general) for a given day, only. He should find on this desk all the apparatus which he needs (or the materials for constructing it), together with notes or directions supplementing, when necessary, the laboratory manual. He should be required to leave his desk as he found it, so as to be ready for the student next behind him in order.

The apparatus, if there is not a complete set for each member of a given section, should be set up for different experiments on different desks, in so far as may be practicable, in progressive order, so that a whole section of students may be moved, at the proper time, each from one desk to the next, without discontinuity, in the case of any student, in the course of experiments followed. Students working more slowly than others should be allowed more time for each exercise, or required to make up, out of hours, for what they have lost, so as to be ready to go on with their work without losing their regular places in their

section. In this way a systematic course of instruction can be given to large sections, with a very limited supply of apparatus, and conflicts in the use of this apparatus may be avoided, with a minimum of planning on the part of the instructor.

It is obvious that, in following any systematic course of experiments with large laboratory sections, supplied with few complete sets of apparatus, either all cannot begin and end with the same experiment, or else some must enter the course later than others. When students differ greatly, as is generally the case in respect to intelligence and preparation, it may be desirable to start them with different exercises; but in the most unfavorable case, a delay of two or three weeks at the beginning of the year is far less objectionable than the confusion which inevitably results from lack of sequence in experiments like those outlined in this book.

It would be impossible within the space which can be devoted to the subject, in this preface, to give a detailed description of the system of instruction recently developed in the laboratories at Berkeley; but it may be pointed out that farther information on this point can be had by those attending the Summer School at the University, or by those visiting the Physical Laboratories. The author will also be glad to answer communications addressed to him on this subject.

The exercises in this book have been developed with care to avoid calling for inferences which are not amply justified by the data before the student. To work out the law, for instance, connecting the length and deflection of a beam has required in the past almost numberless experiments on the part of scientific men. A single pair of observations made by a student can serve at the most to enable him to select, out of several laws suggested to him, one which satisfies the conditions of his experiment. One of the questions on this exercise is put to the student, accordingly, in this form:— IF the deflection of a beam is proportional to SOME INTEGRAL POWER of its length, what is the power in

question? It is practically easier for the student to work this out by experiment than to look it up in a text-book; and by not telling him WHICH power to expect, some point of interest is given to his work.

Care has been taken in so far as possible to avoid exercises which can serve for the purpose of ILLUSTRATION ONLY. If an experiment is "a question put to Nature," then a good experiment is one which enables the student to answer one or more questions that he could not answer beforehand. Most of the questions appended to exercises in this book have been found by practical tests to be of this nature. It is though that similar tests should be applied to experiments performed in the schools. When students are unable, after performing an exercise, to answer the questions which it is intended to illustrate, the exercise has been useless as far as they are concerned. If, on the other hand, they are able to answer these questions beforehand, the exercise is needless, and they should be allowed to substitute some other piece of work.

The author is indebted to Mr. E. R. Drew, instructor in physics in this University, for valuable aid in the preparation of the course of exercises here outlined, and for revision of the manuscript. Thanks are also due to every member of the Physical Department for numerous suggestions and hearty coöperation in the development of the course. In the expectation of revising or reprinting these directions for exercises in physics from year to year, suggestions from all sources will be gladly received.

HAROLD WHITING.

BERKELEY, CALIFORNIA, May 1st, 1894.

EXERCISES

IN

ELEMENTARY PHYSICS.

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1. METRIC AND ENGLISH MEASURES.

APPARATUS: A set of Avoirdupois weights, a set of Metric weights, (to 1 d. g.); trip scales; two metre rods in inches and in mm. A spring balance graduated in decimal multiples of a dyne.

I. Find the weight in grams of several avoirdupois standards. Adjust to 0. 1 gram in each case. Calculate the value of the pound, ounce, and grain in grams. Retain four figures in each result.

If the results of weighing the different standards do not agree, select the best as a basis for your calculations, or if two or more weighings seem equally reliable, average the results. Why do you prefer a weighing with large weights to one with small weights?

Would the results of weighing be affected by an increase or diminution in the earth's attraction for the bodies in question? Give reasons for your answer.

II. Lay a metre rod graduated in millimetres beside one graduated in inches and eighths, so that the two scales meet. Make the 5-inch division coincide with the 127th mm. division. What other inch divisions coincide exactly with the mm. divisions next to them? and with what mm.

divisions do they each coincide? Calculate from several of these data the value of the inch in millimetres. Carry out your work to three places of decimals. Why do you prefer to base your calculation on a comparison involving a large number of inches and millimetres?

III. Why is it unnecessary to make a comparison of the units of time employed in the Metric and English systems?

IV. Find, by suspension from a spring balance, the weight in dynes. of several Avoirdupois standards, also that of several Metric standards of mass.

Calculate the weight of one gram in dynes. How would this be affected (if at all) by an increase or diminution in the earth's gravity? (ask if you do know.)

What kind of instrument would you use to find the mass (or weight in grams) of a body, and what kind of instrument would you employ for a measurement of the weight in dynes of (or force exerted by gravity upon) a body? and why?

Give some idea of a numerical measure of the earth's gravity suggested by your observations.

2. DENSITY.

Apparatus: A wooden block, 1 decim. cube; a similar block loaded with shot; a mould to fit the same; a hollow decim. cube; scales and weights to 1 gram; a vessel with shot for counterpoising; a metre rod; a pail for water; a mop cloth; access to a vernier gauge, to an air-pump, and to supplies of water, coal-oil and gas.

I. Find the length, breadth and thickness of the block of wood by the vernier scale. If the measurements of a given dimension differ, record the mean (or average). Ask for instructions (if necessary) as to the use of the vernier scale. Weigh the block on the balance to one gram. Calculate the surface of the block in square centimetres, its volume in cubic centimetres, and its density in grams per cubic centimetre.

II. Repeat I. with a hollow block, loaded with shot, so as neither to rise nor sink when immersed in water.

Note. If the loaded block and the solid block both fit the same mould, the measurements of length, breadth and thickness in I. need not be repeated.

III. Find the inside measurements of the rectangular mould.

Note. If the block fits the mould, the measurements of the block may be taken for those of the mould.

Place the mould on the balance, counterpoise it with shot, fill with water by means of a small beaker, and find the weight of the water within one gram.

Calculate the density of the water to three decimal places. (Repeat until the result lies between .990 and 1.020). What relation exists between the density of water and that of a loaded block (see II.) which neither rises nor sinks in the water?

Dip some of the water out of the mould by means of the small beaker, held lip downward while being lowered, so as not to cause overflow. Then pour away the rest of the water, and dry the mould with a cloth.

IV. Repeat III. with coal-oil instead of water. Calculate the density of the coal-oil, and also its relative density or specific gravity referred to water, calling the density of water 0.998.

V. Find roughly the capacity of a hollow brass cube by outside measurements, allowing, as well as may be, for the thickness of the brass.

Counterpoise, approximately, by lead shot.

Exhaust as much air as possible by the air-pump. (About 20 strokes will do).

Counterpoise, again, only more exactly, with lead shot, noticing whether the cube has gained or lost in weight.

Exhaust with the air-pump until the weight becomes constant. This is shown by the agreement of two successive weighings.

Admit air, and find the gain in weight within ONE DECIGRAM.

Calculate the density of the air.

VI. Pass a current of coal-gas through the cube until the lighted jet shows a white flame. Find the difference of the weights of the cube with coal-gas and with air within ONE DECIGRAM.

Calculate the density of the coal-gas, also its specific gravity referred to air of the same temperature.

3. DISPLACEMENT.

Apparatus: A glass ball, a wire cage for ditto.; an overflow beaker; a ring stand; a 4 oz. beaker; a vessel with shot for counterpoising; scales and weights; water and coal-oil.

I. Weigh the glass ball to a gram. Fill the overflow-beaker with water until it runs out of the spout, and catch the overflow in a smaller beaker. Empty this beaker, and counterpoise it with shot. Replace it beneath the spout. Lower the ball in its cage into the overflow-beaker, and catch the overflow. Replace the beaker on the scales, to find the weight of the overflow. Answer the following questions:

What takes place when the ball is lowered into the overflow-beaker? How can you find the weight of the water displaced by a body, (i. e. the weight of an equal bulk of water)?

How should the experiment be modified so that the weight of water displaced by the wire cage may not be added to that displaced by the ball?

Find the specific gravity of the glass ball by this experiment.

II. Hang up the glass ball on a stand resting on one pan of the balance, counterpoise it with lead shot, and then surround it with water in a beaker supported by the hand, so as not to touch the ball. Add weights to the lighter side of the balance until equilibrium is restored.

Does the ball gain or lose in weight when thus immersed in water?

Does the gain or loss of weight appear to be much greater, much less, or about the same as the weight of water displaced by the ball in I.? How could the effect of the cage be eliminated?

Find the specific gravity of a ball by the method in II., combined with the weighing of the ball in I.

III. Place a beaker half-filled with water on the scales. Counterpoise it with lead shot. Lower the glass ball into the water so as to be completely immersed, but not to touch the sides or bottom of the beaker. Add weights to produce equilibrium.

Does the beaker gain or lose in weight when the ball is lowered into it?

What relation exists between the gain and loss of weight and other quantities previously determined?

Find the specific gravity of the ball by the data in III. combined with the weight of the ball.

How should the method in III. be modified so as to eliminate the effect of the wire cage?

Which of the three methods seems to you the best, in view of the simplicity of apparatus, universal applicability, and accuracy of results?

IV. Repeat I., II., and III., if time permits, with coal-oil instead of water, and calculate the specific gravity of the coal-oil from the results of each method, instead of calculating the specific gravity of the ball.

4. SPECIFIC GRAVITY BOTTLE.

Apparatus: An 8-oz. wide mouth bottle with solid glass stopper; scales with weight from 1 kilo. to 1 decigram; a vessel with lead shot for counterpoising; sand, salt, water and coal-oil; a drying cloth.

Note. Always weigh the bottle WITH the stopper, or counterpoise it WITH the stopper. Keep the outside of the bottle clean and dry. Dry the inside of the bottle with cotton waste after weighing with liquid. In putting the stopper in place when the bottle contains liquid, tip the bottle and stopper one side, so as to allow air-bubbles to escape.

I. Counterpoise the bottle with shot, fill with water, and find the weight of the water.

Calculate the capacity of the bottle in cubic centimetres, allowing 1.002 cu. cm. to the gram.

II. Repeat I. with coal-oil instead of water. Calculate the specific gravity of the coal-oil.

III. Nearly fill the bottle with sand, and find the weight of the sand in the bottle. (This is more accurate than weighing the sand separately, on account of the danger of spilling).

IV. Counterpoise the bottle containing the sand, by means of lead shot. Fill the spaces between the particles of sand, and above the sand, with water; and shake the contents once or twice so as to free bubbles of air. Find the weight of the water necessary to fill that part of the bottle which is not occupied by the sand.

Why is the weight of water in the bottle less in IV. than in I.?

How can you find the weight of water displaced by the sand?

Calculate the specific gravity of the sand.

V. Dry the bottle carefully, and repeat III. with common salt, or any salt soluble in water.

VI. Repeat IV. with the salt in V. instead of sand, and with coal-oil instead of water.

Why could not water be used in VI. as in IV., instead of coal-oil?

Find the weight of coal-oil displaced by the salt, also the specific gravity of the salt referred to the coal-oil.

Knowing the specific gravity of coal-oil, from II., how can you find the weight of an equal bulk of water?

Calculate the specific gravity of the salt from its weight as compared with that of an equal bulk of water.

What is the algebraic relation between (a) the specific gravity of salt referred to coal-oil, (b) the specific gravity of coal-oil referred to water and (c) the specific gravity of salt referred to water?

5. JOLLY BALANCE.

Apparatus: A Jolly balance, (including beaker and metre rod), with weights from 1 to 5 grams; pieces of glass weighing BETWEEN 3 and 4 or between 4 and 5 grams; water and coal-oil.

I. Fill the beaker with water, place it on the adjustable shelf, and raise or lower the shelf until the lower pan and a definite portion of the wire by which it is suspended are immersed. ALWAYS ADJUST IN THIS WAY, whether a weighing is to be made in air or in water.

Read the balance by the horizontal ring, holding the eye so that the nearer and farther limits of the ring coincide in direction—in other words, sighting along the plane of the ring. Estimate if possible the tenths of millimetres indicated upon the vertical scale of mm.

Repeat the reading with 1, 2, 3, 4, and 5 grams in the upper pan. Do not weigh objects heavier than 5 grams, lest the elastic limits of the spring should be exceeded.

Read again with a small piece of glass in the upper pan.

Read again with the piece of glass in the lower pan.

Calculate by interpolation the weight in grams of the glass in air, and in water; also the specific gravity of the glass referred to the water.

II. Repeat I. with coal-oil instead of water, only instead of calculating the specific gravity of the glass referred to the coal-oil, calculate that of the coal-oil referred to water.

6. NICHOLSON'S HYDROMETER.

APPARATUS: A Nicholson's hydrometer, with jar and with weights from 20 grams to 1 centigram; two small objects, one denser, the other less dense than water.

I. Find the weight necessary to sink the Nicholson's hydrometer to a given mark on the stem, one or two cm. above the body of the instrument. Take care to keep the weights dry. See that the water is not deep enough to allow the upper pan to be submerged. Keep the hydrometer in the middle of the jar, to avoid friction. Adjust the weights to 1 centigram.

II. Repeat I. with a marble in the upper pan. Why does it take less weight than before to sink the instrument to the mark? Calculate the weight of the marble from the data already obtained.

III. Repeat II. with the marble in the lower pan. Is the weight required to sink the instrument greater or less than when the marble was in the upper pan? and why? Calculate the weight of the marble in water, its loss of weight in water, the weight of a quantity of water equal to the marble in bulk, and the specific gravity of the marble referred to the water.

IV. Repeat II.–III. with a piece of cork instead of a marble. Suspend the lower pan upside down, and place the cork beneath it in weighing in water.

Is the weight of the cork in water positive or negative? Is the weight of water displaced by the cork the numerical or the algebraic difference between the weights of the cork in air and in water? Find the specific gravity of the cork referred to the water.

V. Reweigh the cork, as in II.

Does the cork gain in weight during these experiments, and why? How would you avoid possible errors from this source?

7. FLOTATION.

Apparatus: A hydrometer jar, a strip of wood, a specific volumenometer, a universal hydrometer; water, alcohol, coal-oil, saline solution, salt, dilute sulphuric acid; a glass tunnel.

I. Place a strip of wood (similar to the wood of the block in Exp. 2,) in a hydrometer jar, and fill the jar with water. Mark the water-level in pencil on the strip. Find the length of the strip, and the length of the portion immersed.

Calculate the specific gravity of the strip referred to the water. How does this compare with the results obtained with the same wood in Exp. 2?

II. Repeat I. with coal-oil instead of water. Does the strip float at the same or at a different depth and why? Calculate the specific gravity of the coal-oil referred to the water.

III. Float a hydrometer showing "specific volumes" in water, and note the reading.

What practical advantages are possessed by this instrument over the crude form of hydrometer used in I. and II.?

IV. Repeat III. with dilute sulphuric acid instead of water.

Calculate the specific gravity of the acid.

V. Find the readings of a "Universal Hydrometer" in water, in coal-oil, and in acid.

How do these readings compare with the specific gravities of those liquids already found?

What advantage is possessed by a "Universal Hydrometer" for the rapid determination of specific gravities?

VI. Make a ten per cent. solution of common salt, (50

grams salt, 450 grams water), and find its specific gravity by the "Universal Hydrometer."

VII. Find the specific gravity of a saline solution of unknown strength.

Is the strength of the solution greater or less than ten per cent.? and why?

Make a rough estimate of the strength of the unknown solution.

VIII. Find the strength of a mixture of alcohol and water by the following table showing per cents. by weight and specific gravities at about 20° C.

	0	1	2	3	4	5	6	7	8	9
0	.998	996	994	993	991	989	988	986	984	983
10	982	980	978	977	976	975	974	972	971	970
20	969	967	966	965	964	962	961	959	958	956
30	954	953	951	949	947	945	943	941	939	938
40	935	933	931	929	927	925	923	921	918	916
50	914	912	910	907	905	903	901	898	896	894
60	891	889	887	884	882	880	877	875	873	870
70	868	866	863	861	858	856	853	851	849	846
80	844	841	839	836	834	831	829	826	823	821
90	818	815	813	810	807	805	802	799	796	793
100	790									

[The first line in this table contains the specific gravity of alcohol from 0% to 9%; the second line from 10% to 19%, etc., etc.]

8. BALANCING COLUMNS.

Apparatus: A metre rod; a beam compass; a U-tube, a W-tube, and a Y-tube (with two beakers); mercury, water, coal-oil, alcohol, and one or more other liquids; a glass tunnel; a piece of fine wire with swab; a slop jar; 3 burette stands to support tubes.

Note. The balancing columns throughout this experiment are supposed to be vertical.

I. Pour some mercury (through a tunnel) into a glass U-tube, until it stands about 5 cm. deep in both arms of the "U," then fill the longer arm of the U-tube with water until the water stands about 13.6 cm. deep. Work out all air-bubbles, if necessary, with a fine wire. Measure the length of the column of water, and the height of each end of the U-shaped column of mercury above the table.

Does the mercury stand at the same level as the water or not? and why?

What differences do you notice between the shapes of the free ends of the two columns?

II. Pour a little more mercury into the shorter arm of the U-tube, so as to raise the level about 5 cm. Repeat measurements as in I.

Is the length of the column of water altered by the addition of the mercury, or is the column of water simply pushed higher up in the tube?

Find by appropriate measurements the length of the column of mercury which balances the column of water both in I. and in II.

III. Fill up the longer arm of the U-tube with water, until it comes within 5 or 10 cm. of the top of the tube. Find the length of the column of water, and that of the column of mercury which balances it.

Calculate the specific gravity of the mercury referred to the water.

IV. Empty the contents of the tube in III. into a jar, and balance, as in III., a column of coal-oil with one of water.

Which liquid should be poured in first? and which should occupy the longer arm of the U-tube?

Calculate the specific gravity of the coal-oil by the principles already worked out. Does this correspond as nearly as might be expected with the results of previous experiments with coal-oil?

V. Why cannot the U-tube already employed be used to find the specific gravity of liquids which mix with water?

Point out the obvious advantages of a W-tube for this purpose.

If the middle part of the W-tube is not very high, why must the balancing columns be added alternately, little by little, instead of all at once, as in IV.?

Balance a column of water against one of alcohol (or one of ammonia) in a W-tube, paying attention to the precaution above.

Why does each liquid stand at two different levels in its own branch of the "W?"

Find by the appropriate measurements, the length of the two balancing columns. (State how you do this).

Calculate the specific gravity of the alcohol (or the ammonia).

VI. Fill one beaker nearly full with water, and another beaker with some saline solution. Place the feet of an inverted Y-tube, one in each beaker. Raise both liquids as far as may be safe or practicable by suction through the stem of the "Y," and close this stem air-tight.

Why does each liquid stand higher in its own branch of the "Y" than in the beaker?

Find by appropriate measurements the lengths of the two balancing columns. (State how you do this).

Calculate the specific gravity of the saline solution.

VII. Which of the three methods above (IV., V., or VI.) is preferable in the case of liquids which do not mix? in the case of liquids which mix, but are not volatile or hygroscopic? in the case of other liquids? Which is the most general method of balancing columns?

Find as in IV., V., or VI. the specific gravity of other liquids, if time permits, using the appropriate method in each case.

9. BAROMETER AND DALTON'S LAW.

Apparatus: A barometer-tube, medicine-dropper; a small glass tunnel; a 150-gram bottle with rubber stopper perforated by glass tube; a rubber bulb with connecting tube; a wire with swab; a burette stand; mercury and ether; a metre rod.

I. Take a barometer-tube at least 80 cm. long, carefully clean and dry it by a wad of cotton on the end of a wire. Pour in mercury little by little, from a small beaker, through a tunnel, until the tube is nearly full. Close the open end of the tube with the finger, and invert several times, so as to collect all air-bubbles into one, then fill completely with mercury. Place the finger once more over the end of the tube, invert the tube; immerse the open end in a small cistern containing mercury at least 2 cm. deep, then remove the finger. What does the mercury do?

II. Replace the finger beneath the open end of the tube while under the mercury in the cistern. Invert the tube several times, so as to "rinse it out with the partial vacuum" which it now contains, then fill up again with mercury, close the end with the finger, invert, and open under the mercury in the cistern as before.

III. Tip the tube sideways until the top is not more than 70 cm. higher than the cistern. Does the mercury completely fill the tube? or is there an air-bubble above the mercury? Repeat II. until all traces of an air-bubble disappear, or until the size of the air-bubble is reduced to a minimum. What kind of a sound does the mercury now make when it strikes the top of the tube? (Be careful not to let it strike too hard).

IV. Find the vertical height of the column of mercury above the level of the mercury in the cistern. What balances

this column of mercury? What is meant by barometric pressure?

V. Fill a medicine-dropper completely with ether, and inject a few drops into the open end of the barometer beneath the mercury in the cistern. Take care not to let any air in. Describe in detail what takes place. Find the new height of the barometric column. Why is this less than before? Calculate the fall of the barometric column caused by the admission of ether. Find the pressure (in cm. of mercury) of ether vapor in a vacuum, at the temperature of the room.

VI. Pour some mercury, to a depth of 2 or 3 cm., into a 150-gram bottle, carefully cleaned and dried. Insert a glass tube, at least 50 cm. long, through a rubber stopper, so as to reach the bottom of the bottle. Take care that the stopper is air tight. Measure the height (if any) of the mercury in the tube above its level in the bottle. Pour some ether into the open end of the tube, until it stands in an unbroken column 30 or 40 cm. deep. (Air-bubbles can be worked out if necessary by a wire). Measure the height of the ether column. Attach a rubber bulb to the open end of the tube, and force a little ether into the bottle. Be careful not to force in any air. What is the effect of introducing the ether?*

VII. Force in more ether, until the top of the ether column stands at its ORIGINAL height, in VI. How does the volume of the air in the flask now compare with its original volume before the introduction of the ether? And how does the pressure within the flask compare with its original pressure? Does all the ether evaporate? Or does it cease to evaporate after a certain amount has been introduced? What is the effect of saturating a given volumn of air with ether vapor?

VIII. Measure the height of the column of mercury in the tube above that in the bottle. Find the increase of pressure within the flask over its pressure in VI., before the

*This method of introducing ether into a manometer is due to Mr. Thorpe.

introduction of ether. How does this increase of pressure compare with the pressure produced by the vapor of ether in a vacuum? (see V.)

Repeat V., VI. and VII. until you feel sure of your last answer.

Are the pressures due to a given vapor at a given temperature approximately equal, whether produced in a vacuum or in the presence of a gas? or do these pressures differ by an amount considerably greater than the probable error of observation?

Note that a correct answer to the last question is equivalent to "DALTON'S LAW".

10. BOILING AND FREEZING-POINTS.

Apparatus: 200 grams of ice, with a hammer and cloth for powdering the same; a dish to melt paraffine, an alcohol lamp, a beaker, two test-tubes (one large, the other small); some saline solution, alcohol and ether.

I. Crush about 100 grams of ice (from the refrigerator, N. W. corner of laboratory) by folding it in a cloth, and striking it with a hammer; place it in a beaker, and find the reading of a thermometer when its bulb is surrounded with the ice.

II. Drain off the water formed by the melting of the ice, and fill the spaces between the fragments of ice with a solution of salt tested in Exp. 7 or 8.

What is the effect of salt in solution upon the freezing-point of water?

III. Melt some paraffine in a porcelain dish by means of an alcohol lamp. Immerse the thermometer bulb in the melted paraffine, remove it, and watch the temperature until the film of paraffine adhering to the bulb becomes whitish. Then note the temperature.

Does the temperature fall uniformly? or is the fall arrested somewhat during solidification? What is the temperature of solidification of the paraffine?

IV. Heat some water in a beaker. Hold the thermometer in the water, so as not to touch the sides of the beaker, and note the temperature when the film of paraffine, adhering to the bulb, becomes transparent.

What is the melting-point of the paraffine? and is this above or below the point of solidification? Repeat III. and IV. until you feel sure of your last answer.

V. Heat some water (about 5 cm. deep) in a test-tube

until it boils. Find the reading of the thermometer in the water, also in the steam above the water.

What is the boiling-point of this water in this test-tube? and is it higher or lower than the point of condensation of the steam? What kind of thermometer have you employed?

VI. Repeat V. with a ten per cent. solution of salt from Exp. 7.

What is the effect of salt in solution on the boiling-point of water?

VII. Heat some water, 5 cm. deep, in a beaker to boiling. Remove it to a safe distance from the flame. Fill a small test-tube 2 or 3 cm. deep with alcohol, and immerse it in the water until it boils. If the water is not hot enough, heat it again, and repeat. Note the temperature at which the alcohol boils.

VIII. Find as in VII. the boiling-point of ether, after the water has cooled to 50° or 60°. Take the boiling-point as soon as possible after the ether begins to boil. Notice whether the boiling-point of the ether is constant or variable during continued ebullition, and explain this on the assumption that the ether contains alcohol, which is less volatile than ether.

11. PRESSURE OF VAPORS.

Apparatus: A large and deep glass jar, containing a U-tube closed at one end; a glass tunnel, a thermometer, and a metre rod; ether, mercury, and access to hot water.

I. Fill a U-tube, closed at one end, with mercury, pouring in the mercury, little by little, from a small beaker, through a tunnel, and working it round the bend in the tube into the closed end, until this and the bend of the tube are filled with mercury.

Pour in 5 or 10 cm. of ether, and tip the tube so as to let about 5 cm. of ether flow round the bend. Work out all bubbles of air. The column of mercury should now stand somewhat lower in the open branch than in the closed branch of the U-tube. The whole column of mercury should be however at least 50 cm. long, including the bend.

Now fill a deep glass jar with water at about 55° Centigrade, from the heater over the sink; stir it thoroughly, and when it has cooled to 50°, place the U-tube, containing the mercury and the emprisoned ether, in the jar.

Describe the phenomena which take place.

II. Hold a thermometer in the jar between the two branches of the U-tube, and on a level with the small column of emprisoned ether. Note the reading of this thermometer; also, at as nearly as possible the same time, the difference in level between the two ends of the mercury column in the two branches of the U-tube.

As the water cools, continue to take simultaneous observations of temperature and pressure as long as may be practicable.

III. Calculate the pressure of the ether vapor in each case (in cm. of mercury), remembering that the barometric pressure is about 76 cm. of mercury.

IV. Plot a curve on coördinate-paper representing the pressure of ether vapor at different temperatures, using the temperatures observed in II. as abscissas, and the corresponding pressures as ordinates.

Find the temperature corresponding to a pressure of 76 cm., and compare it with the boiling-point of the ether observed in Exp. 10. Why should these results agree?

Find the pressure corresponding to the boiling-point of the ether, and compare this with the barometric pressure. Why should these two results agree?

V. Repeat I.–IV., if time permits, with alcohol, or other liquid, after consultation with your instructor.

12. HYGROMETRY.

Apparatus: An air-pump, a graduated bottle, a battery jar, a rubber tube, a drying-tube, trip scales, weights (1 k. to 1 dg.); a polished metal cup, a thermometer, ice (or nitrate of ammonia) and a pair of wet-and-dry-bulb thermometers. Access to sink and to air-pump.

I. (1) To be performed at the sink.—Fill a graduated bottle with water, invert in a battery jar full of water, push a rubber tube down into the jar and up 5 or 10 cm. into the mouth of the bottle, and empty most of the water out of the jar. Repeat until hardly any air is found in the bottle.

(2) At the air-pump. — Pull out the piston of the air-pump to its fullest extent; connect the vent with the rubber tube in (1), and force as much air as can be measured into the graduated bottle.

Fill the bottle again, if necessary, as in (1), and measure the air remaining in the barrel of the air-pump as above.

Express the contents of the barrel in cu. cm.

II. Carefully counterpoise a drying tube (consisting of a U-tube filled with glass beads wet with sulphuric acid) on the trip scales. Lay it flat with its centre of gravity over the middle of the scale-pan, taking care not to let any of the acid flow out.

Force 100 barrel-fuls of air from the air-pump through the tube, and find the gain of weight due to absorption of aqueous vapor from the air.

Calculate the weight of water in 1 cu. cm. of air.

III. Cool some water in a polished metal cup, by stirring in ice, little by little, until a film of moisture appears on the outside. Be careful not to breathe on the cup. If you feel doubtful about the existence of a film, see if you

can wipe it off in places with your handkerchief. Note the temperature at which a film appears.

IV. Add water from the faucet, little by little, until the film disappears. Note the temperature at which this occurs.

V. Repeat III. and IV. alternately until the temperatures of appearance and disappearance of the film agree within one or two degrees. Find the mean of these two temperatures, and note that it is called the "dew-point" of the air.

VI. Note the reading of the dry-bulb and wet-bulb thermometers.

Which stands the lower? And why? Find the difference of the two thermometers, multiply it by 1.8, and subtract the product from the reading of the dry-bulb thermometer. How does the result compare with the dew-point determined in V?

Note. While one pair of students is performing I.–II., another pair may perform III.–VI., and the reverse.

13. PNEUMATICS.

APPARATUS: *An air-thermometer, of special construction, a mercurial thermometer, a jar for water, a beaker, and a rubber siphon.

I. Place both sliders with their upper edges opposite the zeros of their mm. scales, then slide the glass gauges within their clamps until the mercury stands at the same level, 0 mm., in both gauges.

Read the space in cu. cm. occupied by the confined air in the closed gauge. (The gauge is graduated to cu. cm. and tenths).

II. Now raise the open gauge until it stands at about 76 cm., readjust the closed gauge to zero as in I., then readjust the open gauge, etc., etc.; until, while the closed gauge stands at zero, the open gauge stands at 76 cm.

Again read the volume of the air confined in the closed gauge. What proportion does the pressure of the confined air in II. bear to that in I.? What proportion does the volume of the confined air in I. bear to that in II.?

III. Repeat II. with modifications necessary to bring the mercury in the open gauge at zero and that in the closed gauge at 25.33 cm.

What proportion does the pressure of the confined air in III. bear to that in I.? What proportion does its volume in I. bear to that in III.?

State whether the law of "Boyle and Mariotte" connecting the pressure and volume of a gas at a constant temperature, is or is not illustrated by your experiments, within the limits of errors of observation.

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*If the old form of apparatus with mirror-scale is used, slight modifications of the directions below will be necessary, and the student should ask for special instruction.

IV. Replace the apparatus as in I., only measure accurately the temperature of the water surrounding the closed gauge. Siphon off this water, and replace with water at about 60° Centigrade. Readjust as in I., and again measure the volume (in cu. cm.) of the confined air, and at the same time, observe the temperature.

Calculate (a) the proportion which the new volume bears to that in I., and (b) the proportion in which it increases for a rise of one degree of temperature. The latter (b) is found by subtracting unity from the result in (a), and dividing the remainder by the rise of temperature in question.

V. Raise the open gauge until the confined air in the closed gauge is compressed to its orginal volume, in I. Note the temperature of the water, and the difference of level between the mercury levels in the two gauges.

What proportion does the pressure of the confined air in V. bear to that in I.? And in what proportion does the pressure of a gas increase, when confined to a constant volume, for one degree rise of temperature?

14. EXPANSION OF LIQUIDS—BALANCING COLUMNS.

Apparatus: An expansion apparatus similar to Gay-Lussac's, a long stirrer, a rubber tube; a metre rod, and a thermometer.

I. Fill the inner system of tubes with water from the faucet, through a rubber tube. When a stream of water issues continuously from the open end, the tubes are probably full. Make sure, however, that no air is caught in the bends of the tubes. Rock the whole apparatus several times from right to left, so as to free the bubbles, if any.

Fill one of the water-jackets with cold water, the other with water as hot as possible. Draw this from the heater near the sink, in a stream so slow that it issues mixed with steam.

Does the water stand at the same height in the two gauges? How do you explain this fact?

II. Stir the hot water thoroughly with the long stirrer, and observe its temperature. At the same time, measure the difference of level between the two glass gauges. Note the temperature of the water in the cold jacket.

III. Pour out a little of the hot water, and replace with cold water; mix thoroughly, and proceed as in II.

IV. Make as in II. and III. a series of simultaneous observations of the difference between the heights of the two hydrostatic columns, and the corresponding temperatures.

V. Plot the results obtained in II. III. & IV. on coördinate paper, laying off the temperatures horizontally, one tenth of an inch to the degree, and the differences of level vertically, one tenth of an inch to a millimetre.

Is the expansion of water uniform or irregular?

VI. Find from your curve the difference between the two columns of cold water in the gauge at 50°. Measure the length of the hot water column from centre to centre of the horizontal bends, and find the length of the cold water column which balances it at 50°, by subtracting the difference between the two columns of cold water in the gauges from the hot water column. (Ask why, if you do not understand this). Calculate the relative density of water at the temperature of the room and at 50°.

Draw a tangent to the curve at a point between 50° and 51°; measure the rise of this tangent in cm. of the scale corresponding to a rise of 10° in temperature. Calculate the expansion in cm. of a column of water 1 cm. long, between 50° and 51°. What is this quantity called? (Ask if you do know).

15. EXPANSION OF LIQUIDS—SPECIFIC GRAVITY BOTTLE.

Apparatus. A glass-stoppered bottle, a thermometer, scales with weights to 1 gram, a vessel for hot water, some coal-oil, some alcohol, and a cloth.

I. Find, as in Exp. 4, the weight of coal-oil required to fill a glass-stoppered bottle. Note the temperature of this coal-oil.

II. Surround the bottle up to its neck with hot water, at about 30 degrees. Take a cloth, and with it wipe off the coal-oil which is forced out of the bottle, from time to time, until no more is forced out. Then take the temperature of the water, after thoroughly stirring it. Take the bottle out of the water, wipe it dry, and find as before the weight of coal-oil which it contains. Why does the bottle hold less coal-oil than before?

III. Repeat II. with water at 40°, then with water at 50°, 60°, etc., up to 100° if possible. Note in each case the temperature and the weight of the coal-oil, determined as before.

IV. Plot the results of II. and III. on coördinate paper; draw a curve representing the weights of coal-oil filling the bottle at different temperatures; prolong this curve by the eye until it reaches the zero of the scale of degrees, and infer the weight of coal-oil which would fill the bottle at 0°.

Prolong the curve also until it intersects the line representing 100°, and infer the weight of coal-oil at 100°, which would fill the bottle.

V. Calculate the relative volume of a given mass of coal-oil at 100° referred to its volume at 0°. Express this as

a ratio, consisting of unity followed by three places of decimals, thus : 1.xxx.

Find the expansion of 1 cu. cm. between 0° and 100°, by substracting 1. from the relative volume above. This will give you a cipher followed by three places of decimals, thus : 0.xxx.

Calculate the expansion of 1 cu. cm. for one degree. Why should this contain five places of decimals? What name is given to this quantity? (Ask if you do not know).

VI. Repeat I.–V. if time permits, with alcohol instead of coal-oil.

16. LINEAR EXPANSION.

Apparatus: An expansion apparatus, with metallic rod, a metre rod, a thermometer, a rubber tube for siphon, vessels for hot and cold water.

I. Find the length of a metallic rod, whose expansion is to be determined, by measuring it with a metre rod divided into mm.

II. Place the rod in the horizontal trough, cover it with water, take the temperature of the water, and set the micrometer upon the rod.

A setting of the micrometer is made as follows: Take hold of the screw by the friction head, which slips when the requisite pressure is attained; turn it to the right until it slips, and see how many whole mm. divisions on the shaft of the screw are uncovered. Read the hundredths of a mm. by the indication of a line parallel to the shaft of the screw with respect to the divisions on the barrel. Repeat until concordant readings are obtained, and record the mean of a considerable number of such readings. In a rod 1000 mm. long, the readings should agree within a few hundredths of a mm.

After each setting, withdraw the point of the micrometer at least 3 mm., so that it may not be injured by expansion of the rod.

III. Siphon off some of the water, and replace with hot water, so as to raise the temperature 10 or 20 degrees.* Note the temperature of the water after thoroughly stirring it, and make a new setting of the micrometer.

IV. Make simultaneous observations of temperature

* The water may also be heated by Bunsen burners placed beneath the trough.

and the micrometer at intervals of 10 or 20 degrees as in III., up to at least 90°.

V. Siphon off some of the hot water, and replace with cold. Make in this way a second series of observations of temperature and length 10 or 20 degrees apart, down to the temperature of the room.

VI. Cool the water with a little ice, and note the temperature and micrometer reading as before.

VII. Plot all the temperatures and corresponding readings of the micrometer on coördinate paper, and draw curves illustrating the expansion and contraction of the rod.

VIII. Calculate the average expansion, in cm., of one cm. of the rod when heated one degree. What name is given to this last result? (Ask if you do not know.)

17. CHANGE OF VOLUME IN MELTING.

Apparatus: A specific gravity bottle, two battery-jars, scales and weights to one gram, a thermometer, and some ice.

I. Mix about 300 grams of crushed ice and about 300 grams of water in a battery jar, and stir till the temperature falls below 1° Centigrade.

Counterpoise a specific gravity bottle, cool it in the mixture of water and ice, and fill it with cold water decanted out of the mixture.

Remove floating particles of ice, if any, and insert the solid glass stopper so as not to include any air. (See Exp. 4.)

Dry the outside of the bottle, and find the weight of cold water which it contains.

II. Empty the cold water back into the jar, and fill the bottle with pieces of ice as full as may be convenient. Insert the stopper loosely, invert the bottle, and let as much water as possible drain off from the ice.

Find the weight of ice contained in the bottle, making the weighing as rapidly as possible. If much of the ice has melted, drain off the water again, and reweigh.

III. Fill the space in the bottle (not occupied by ice) with water from the jar at about 0°, and reweigh the bottle.

Calculate as in Exp. 4, the specific gravity of the ice referred to water at about 0°.

IV. Place the bottle with its contents in a jar of water at about 30°. Warm it in this way until all the ice is melted, and until the mixture, after being well shaken, shows a temperature of 8°. Weigh the bottle and its contents.

Has any change of volume taken place? and if so, what kind of a change?

V. Fill the bottle with cold water at 8°, and reweigh it.

How does the density of water at 8° compare with that at 0°?

Find the contraction of the ice in cu. cm., allowing 1.000 cu. cm. to the gram of water at 8°.

Calculate the contraction of one gram of ice in melting.

18. LATENT HEAT.

Apparatus: A Bunsen burner, with cone; a filter stand, with ring and netting; a pint cup, a thermometer, a clock, and some ice.

Note. The height of the flame must not be disturbed throughout the experiment.

I. Nearly fill a pint cup with crushed ice; drain off as much water as possible, and note the temperature.

Put an iron cone on a Bunsen burner, to steady the flame; light the flame and turn it down until its extreme length is about 10 cm. Set it beneath a netting 1 or 2 cm. above the top of the cone. Heat the ice for just one minute. Remove the cup, and again note the temperature. Stir the ice with your pencil, not with the glass thermometer. Note the temperature after stirring.

Is stirring necessary to secure uniformity of temperature in a mixture? Has the minute's heating raised or lowered the temperature of the ice? How do you account for this fact?

What change of state has taken place in part of the ice?

II. Heat the ice for another minute, and proceed as in I. What farther change has taken place?

III. Proceed as in II. to heat the ice one minute at a time until after thorough stirring a distinct rise of temperature is observed. Note the temperature of the mixture.

What proportion of ice now remains in the cup?

IV. Place the cup with its contents over the burner as before, and note the temperature at intervals of one minute until the water boils, stirring between observations, but not removing the cup.

How does the time required to melt the ice compare with

the time required to raise the water, formed by its liquefaction, from 0° to 100° Centigrade?

If the rate of heating is uniform, how does the heat required to melt a given weight of ice compare with that required to raise the same weight of water from the freezing to the boiling temperature?

Calling the amount of heat necessary to raise a gram of water one hundred degrees one hundred units, about how many units of heat are necessary to melt one gram of ice?

V. See how long it takes to boil all the water away with the same flame. Note the temperature from time to time. EXTINGUISH THE FLAME AS SOON AS THE WATER DISAPPEARS.

Calculate, by the same process of reasoning as in IV., the number of units of heat necessary to convert one gram of water into steam. What name is given to this last quantity? to the corresponding quantity in IV.?

VI. Plot all the results in I.–V. on coördinate paper, allowing 0.1 inch, horizontally, for one minute, and 0.1 inch, vertically, for 5 degrees.

19. SPECIFIC HEAT—METHOD OF FUSION.

Apparatus: Three or more balls of different materials, weighing about 100 grams, each; a Bunsen burner, a filter-stand, with ring; vessel for heating water; trip-scales; weights from 1000 to 0.1 grams. A block of ice. Cotton "waste," or cotton "batting".

I. Suspend several balls of different materials, but of about the same weight, in a vessel of boiling water.

Hollow out a cavity in a cake of ice sufficient to contain the largest ball. Wipe the cavity dry with cotton fibre, and place one of the balls in the cavity. The transfer from the boiling water to the cavity in the ice should be made as rapidly as possible, so as to avoid considerable loss of heat.

Weigh off some cotton, previously wet and wrung out as dry as possible; cover the ball with this cotton, so as to cut off air-currents; wipe up all the water formed by the melting of the ice, and find the amount thus melted by reweighing the cotton.

Find the weight of the ball.

II. Repeat I. with each of the balls. Answer the following questions:

1. Does a given weight of metal at a given temperature always melt a given amount of ice? or does the amount melted depend upon the material?

2. How many units of heat were given out by each ball? Assume that (as you might have found in Exp. 18) one gram of ice requires about 80 units of heat for its liquefaction.

3. How many units of heat are given out by each ball, on the average, in falling one degree in temperature?

4. How many units of heat are given out by one gram in falling 100 degrees in the case of each ball?

5. How many units of heat are given out, in each case, by one gram in falling one degree?

6. Which of the quantities above represents the thermal capacity of the ball? and which represents its specific heat?

20. SPECIFIC HEAT OF LIQUIDS.

APPARATUS: A tin or other metallic cup; a Bunsen burner; a filter stand; a tumbler; a thermometer; a copper spiral; a balance, and weights. Liquids to be tested.

I. Half fill a pint cup with water, and heat the water to boiling, over a Bunsen burner. Immerse a copper spiral in the boiling water.

Weigh off in a beaker enough water to cover the copper spiral, and note the temperature of the water.

Lift the copper spiral out of the boiling water, jerk off as much water as possible, and lower it immediately into the beaker of cold water. Stir the water with the spiral for about one minute, both up and down and sideways. Note the temperature of the water.

Is the water warmer or cooler than before? And why?

II. Repeat I. with as nearly as possible the same weight of coal-oil instead of cold water in the beaker.

Is the coal-oil raised in temperature more or less than the same weight of water? About how many times more or less? Try to estimate about how much coal-oil would be raised in temperature just as much as the water.

III. Repeat II. with as much coal-oil as you think will show the same rise of temperature as the water in I.

Is the quantity of coal-oil used too great or too small? Give reasons for your answer. Calculate by a comparison of the results in II. and III., just how much coal-oil would be equivalent in thermal capacity to the water.

Calculate also the quantity of water which would be equivalent to one gram of coal-oil in thermal capacity. What name is given to this quantity?

Why does not the heat absorbed by the beaker affect the results above?

Why are these results unaffected by cooling of the spiral? or by cooling of the sides of the beaker in contact with the air?

IV. Repeat I.—III., or such parts of I.—III. as may be necessary, in order to find the specific heats of alcohol, glycerine, and as many other liquids as time may permit.

21. MECHANICAL EQUIVALENT OF HEAT.

Apparatus: A metre rod; a pasteboard tube; a thermometer; two bottles, containing each one kilogram of shot; access to the refrigerator.

I. Place a kilogram of lead shot in a bottle and set it to cool in the refrigerator. When the shot has cooled about 3° below the temperature of the room, take the temperature accurately (within a tenth of a degree if possible), and pour it into the long pasteboard tube provided for this experiment. See that the tube is securely closed.

Raise one end of the tube, letting the other rest upon the table, until the tube stands vertical. Do this so rapidly that the shot is held in its place by centrifugal force until it reaches its highest point. Then stop the motion as suddenly as possible by the force of the hand (not by a blow). The shot should fall the whole length of the tube almost like a solid mass.

Repeat this operation until the shot has fallen through the whole length of the tube one hundred times. Insert a thermometer into the mass of the shot, through a small opening made for this purpose, and note the temperature. Why has the temperature risen above that of the room?

Measure the average distance through which the shot falls in each case. Should the metre rod just touch the shot in this measurement? or should it be driven into the mass of the shot? How do you allow for the thickness of the stopper?

Calculate the total distance through which the shot has fallen, and the distance through which it would have to fall to be raised one degree in temperature. How great a distance would one gram of shot have to fall to raise its temperature by the same amount (one degree)? How much

work in gram-centimetres would be required to raise a gram of shot one degree in temperature? How much work would be required to raise one gram of water one degree in temperature, if the specific heat of lead shot is 0.032? What name is given to this last quantity?

II. Repeat I. while the tube is still warm from the first experiment. Is the rise of temperature greater or less than before?

III. Repeat until concordant results are obtained. While performing one experiment, cool the shot for the next, so that the tube may not have time to cool in the mean time. Explain how the thermal capacity of the tube is eliminated in this way. As soon as the rise of temperature of the shot becomes approximately known, cool the shot for the next experiment just half of this amount. How does the average temperature now compare with that of the room? Why is the effect of cooling eliminated?

22. ABSOLUTE HEAT CONDUCTIVITY.

Apparatus: A conduction apparatus; a small beaker; a steam generator with Bunsen burner and rubber connecting tube; two thermometers; scales and weights from 1000 g. to 0.1 g.; a kilo. of ice; access to hammer and cloth for powdering ice; access to clock.

I. Fill, with crushed ice, that end of the conduction apparatus which is provided with a single drainage tube, and find the weight of ice melted in ten minutes, then in another ten minutes, then in a third ten minutes, etc., etc., until (by the agreement of two successive results) the rate of melting is known to be constant.

Calculate the rate of melting in grams per minute, due to conduction through the sides of the apparatus, convection of air-currents, etc.

II. Fill a steam generator two thirds full of water, place a Bunsen flame beneath it, and raise the water to boiling.

Turn the spout so that any overflow of water may do as little damage as possible. When a jet of pure steam issues from the spout, remove the flame for a short time; fit a rubber tube over the spout, and connect the other end of the tube with the conduction apparatus. Replace the burner beneath the steam generator.

Find as before the weights of ice melted in successive periods of ten minutes each, until the rate of melting becomes constant; and calculate the rate of melting as before, in grams per minute.

Why is the rate of melting more rapid in II. than in I.?

III. Place two thermometers in the holes provided for this purpose, while the steam is still running through the apparatus; and find in this way the difference of temperature between two points in the metallic rod, through which the

greater part of the heat is conducted from the steam chamber to the ice chamber. Measure the distance between these holes, and the diameter of the rod.

Calculate the cross-section of the rod in square centimetres, and the number of units of heat which flow through the rod in 1 second, remembering that it takes about 80 units of heat to melt one gram of ice, and 60 sec. to make 1 minute.

Calculate the difference in temperature between the two points in the rod, and the difference in temperature between two points one cm. apart, by simple proportion.

Calculate the number of heat units which would flow through a rod of the same material one sq. cm. in cross-section with a difference of temperature amounting to one degree per cm., assuming that the flow of heat is proportional to the cross-section and to the difference of temperature per cm.

What name is given to this latter quantity? (Ask if you do not know).

23. RELATIVE CONDUCTIVITY AND DIFFUSIVITY.

Apparatus: A rod half iron, half brass, ruled in inches; a similar rod constructed of two other metals; lead shot and bees' wax; a Bunsen burner; an Ingenhousz' apparatus; a thermometer; access to hot water, and to a clock.

I. Fill the Ingenhousz' apparatus with water at 60°. When the wax on the several rods has melted as far as it will melt,—say after 5, 10, or 15 minutes,—note the distance through which it has melted on each rod. This can be determined by the touch within a centimetre or less.

Arrange the different materials of which the rods are composed in their order of conductivity.

II. Repeat I. with water at 70°, at 80°, etc. How do the results thus obtained compare with those in I.?

III. Fasten a row of lead balls one inch apart with bees' wax to a rod of iron and brass joined in the middle. Heat the junction by a Bunsen burner. Note the time it takes to melt off each ball.

Does iron or brass diffuse temperature the more rapidly? Calculate the relative rates of diffusion of temperature from the observed times required to melt off the first, second, and third ball in the case of each metal. What name is given to that property in solids which enables them to diffuse temperature rapidly?

IV. Repeat III. with a rod similar to that in III., but composed of two other metals.

V. Show that differences between relative conductivity and relative diffusivity may be explained as the result of differences in specific heat.

VI. Point out any differences which may be apparent between the order of conductivity and the order of diffusivity in different metals.

24. RADIOMETRY.

APPARATUS : Two similar metallic vessels, one polished, the other blackened; a large beaker; a lamp, a thermometer, and a metre rod; access to clock.

I. Hold your hand near one side of the lighted flame, then above it. Note any difference in warmth that may be felt.

Now put your hand in the glass beaker, and repeat the experiment, taking care not to crack the glass by bringing it too near the flame. Can heat be felt through the glass instantly, or only after the glass has had time to become warm?

What reason have you for thinking that air-currents are concerned in carrying some of the heat in certain directions?

What reason have you for thinking that air currents are not the sole means of carrying heat?

Why cannot the transference of heat through the glass be explained by the ordinary (slow) process of conduction?

Explain the separate functions of conduction, convection, and radiation in this experiment.

II. Fill the polished and the blackened metallic vessels with boiling water, and note the temperature of each for several minutes. Which cools the more rapidly and why? (Ask if you do not know).

Give some idea of the relative magnitude of the cooling effects due to convection and radiation.

III. Fill both the polished and the blackened metallic vessels with cold water, and set them in the sun, or at the same distance from the lamp-flame—say 3 inches.

Which vessel is warmed the more rapidly and why? Taking this single case as an instance of a general law, state

whether the best radiators are the best absorbers of radiant heat, or the reverse.

IV. Bring the blackened metallic vessel filled with cold water as near as practicable to the flame, and find, by observations lasting a suitable length of time, the average rate of increase of temperature in one minute.

Then repeat the observations at twice the distance from the centre of the flame.

If the radiation of heat is proportional to some integral power of the distance, directly or inversely, what is the power in question?

25. RUMFORD'S PHOTOMETER.

Apparatus: A screen with rod to cast shadow; a group of four candles; a single candle; a coal-oil lamp; a metre rod; scales and weights from 1 kilo. to 1 gram; access to a clock.

I. Set the screen in such a position that the light from the windows casts no shadow of the rod upon it. Light the single candle, set it at a distance of 50 cm. from the screen, and so as to cast a shadow of the rod near the middle of the screen, but wholly on one side of the middle point. Light the group of four candles, and trim their wicks so that the height of the flames may be as nearly as possible equal to that of the single candle. Repeat this adjustment from time to time throughout the experiment.

Set the group of four candles at such a distance and in such a direction from the screen as to cast a shadow of equal intensity with, and adjacent to, that cast by the single candle. Measure carefully the average distance of the group of four candles from the screen. Repeat I. until concordant results are obtained.

How do you know that two lights, casting shadows of equal intensity upon a screen, produce upon this screen equal degrees of illumination?

Assuming that the light of four candles is four times as great as that of a single candle, and that brilliancy of illumination varies directly or inversely as some power of the distance, what is the power in question? And is the variation direct or inverse? What is the law connecting the candle-power of each light with the distance at which equal brilliancy of illumination is produced?

II. Repeat I. with the group of four candles at a distance

of 50 cm. from the screen, and adjusting the distance of the single candle until shadows of equal intensity are produced.

III. Find by appropriate measurements the candle-power of a coal-oil lamp, by comparison with the group of four candles.

IV. Find the rate of consumption of the group of candles and of the lamp in III. in grams per minute, by observing in each case the loss of weight in a given time.

Calculate from III. and IV. the relative illuminating power of the candles and the lamp for equal weights consumed.

26. COLOR PHOTOMETRY.

Apparatus: A lamp; a white screen; colored papers; transparent red, green and violet glasses or shields; a metre rod; a set of Maxwell's discs, with rotating stand; and access to a dark room.

I. Hold a piece of red paper between the lamp and the white screen (in the dark room), at such a distance from the lamp that the red paper seems as brightly illuminated as the white screen does (in parts not shaded by the red paper) when viewed through a piece of red glass.

Measure the distance of the paper and that of the white screen from the centre of the lamp-flame.

Calculate from these distances the relative proportion of red light reflected by the colored paper and by the white screen, making use of the law connecting brilliancy of illumination with distance, already worked out. (See Exp. 25).

II. Find as in I. the amount of green light (if any) reflected by the red surface, substituting for this purpose a piece of green glass instead of a piece of red glass in front of the eye.

III. Find as in I. the relative amount of violet light reflected by the red surface, making use of a violet shield (consisting of a solution of sulphate of copper in ammonia).

IV. Repeat I., II. and III. with a piece of green paper.

V. Repeat I., II. and III. with a piece of ultramarine blue paper.

VI. Repeat I., II. and III. with pieces of differently colored papers.

VII. Take a piece of colored paper tested in VI., and mount it on a small Maxwell's disc. Interlock with it black and white discs of the same size. Interlock three large

discs, red, green and blue, to correspond with the colors tested in I.—V., also a black disc, and mount all seven discs on the rotating stand, the small discs in front of the large discs.

Expose sectors of red, green, and blue to correspond with the proportions of red, green and violet light already found in the paper tested in VI. See whether the disc covered with this paper matches the larger discs in color when rotated rapidly. If not, make them match as nearly as possible (a) by throwing in more black into the central or into the peripheral portions; (b) by throwing more or less white into the central portion, and (c) by changing the proportion of red, green and blue.

How does the average amount of red in the outer parts compare with that in the inner circle? How in the same way do the amounts of green and violet compare?

27. FOCI OF MIRRORS.

Apparatus: A concave mirror; two candles, a screen and a metre rod.

I. Focus the window bars (looking west) on the screen, by means of the concave mirror. Measure the distance from the mirror to the screen. Then focus the trees or buildings in the extreme distance upon the screen. Again measure the distance of the mirror from the screen. Must the distance between the mirror and the screen be increased or decreased to bring this change about? Which of the distances measured is equal to the "principal focal length" of the mirror? Is it accurate enough to make use of the window-bars in finding the principal focal length of the mirror?

II. Place the screen at a distance from the mirror equal to twice its principal focal length. Light a candle, and set it as close to the screen as can be done without danger of burning it. Turn the mirror until the image of the candle nearly coincides with the candle itself, and adjust the distance of the screen from the mirror, if necessary, so as to give the sharpest possible definition. What is the radius of curvature of the mirror? and why?

III. Light a second candle, set it at a measured distance —about 6 inches—from the first candle, and as near the screen as may be practicable. How does the distance between the images of the two candles compare with that between the candles themselves?

IV. Place the screen at a distance from the mirror equal to five times its principal focal length. Turn the mirror, if necessary, so as to form two spots of light on the screen, then move the candles to or from the mirror (note which) until a clear focus is obtained. Measure the distance of

the candles from the mirror. Measure also the distance between the images of the candles, and between the candles themselves.

How does the proportion which the distance between the candles bears to the distance between their images compare with the proportion which the distance between the candles and the mirror bears to the distance between the images and the mirror? How (if at all) would you modify the statement in the last question if the distances of the candles and their images were to be measured from the centre of curvature of the mirror (see II.) instead of from the mirror itself?

Find a relation between the reciprocals of the distances of the candles and their images from the mirror, the reciprocal of the principal focal length of the mirror, and the reciprocal of the radius of curvature.

V. Repeat IV. with the positions of the candles and the screen interchanged. Answer all the questions under IV. anew.

28. FOCI OF LENSES.

Apparatus: A converging lens, a screen, two candles, a metre rod and access to a window with a distant view.

I. Focus the window-bars (looking west) on the screen by means of the converging lens, and measure the distance between the lens and the screen. Then focus the trees, etc., in the extreme distance. Again measure the distance of the lens from the screen. Must the lens and the screen be made to approach or to recede in order to bring this change about? Which of the measurements represents the "principal focal length" of the lens? Is it accurate enough to use window-bars in finding the principal focal length of a lens?

II. Light two candles, place them at a measured distance —about six inches—from each other in the middle of the table, and set the lens at a measured distance from the candles equal to twice the principal focal length of the lens. (See I.) Set the screen so that the candles will be focussed upon it. Measure the distance of the lens from the screen, also the distance between the images of the candles.

How do the distances of the lens from the screen and from the candles compare? How does the distance between the images of the candles compare, under these circumstances, with the distance between the candles themselves?

III. Place the lens at a measured distance from the candles equal to five times the principal focal length of the lens, and move the screen so that both candles are focussed upon it. Measure the distance from the lens to the screen, also the distances between the candles and between their images.

Find a proportion between the four distances in question. Find also a relation between the reciprocals of the distances

of the lens from the candles, and from the screen, and the reciprocal of the principal focal length of the lens.

IV. Repeat III. with the distances of the lens from the screen and from the candles interchanged. How is the proportion in III., and how is the relation between the reciprocals in III. affected by this interchange?

V. State all points of analogy and difference which may become obvious on comparing this with the preceding exercise (Exps. 27 and 28).

29. PHOTOGRAPHIC CAMERA.

Apparatus: A photographic camera, with a tripod; a plate-holder; two plates; two trays; 10 g. ferrous sulphate; 30 g. potassic oxalate; 15 g. sodic hyposulphite; 3 beakers; a steel "diamond;" access to dark room with ruby light and water.

I. Trying the plate-holder. Practice this with a discarded plate, in the light, until you become used to the plate-holder. Be sure that the slide fits perfectly, so as to leave no crack through which light may enter. Mark a line showing how far the slide must be drawn out before the plate begins to be exposed, and another line to show how far it must be drawn out to expose the whole plate. Divide this distance into 12 parts. Practice cutting up a discarded plate into strips with a diamond applied to the glass (not film) side of the plate.

II. Putting a plate in the plate-holder. Ask for a red light in the dark room; take a box of plates in with you, close the door and see that no one opens it during this process. Close up chinks, in so far as possible, so as to exclude all white light from the room. Open the box of plates, and remove the black paper from one or more of them. Take out one plate, handling it by the edges, and being careful not to touch the film side. Lay the plate in the plate-holder, film side out, and close the slide. Return the rest of the plates, carefully wrapped up, as you found them to their box, and put on the cover (or covers) of the box. The door may now be opened.

III. Adjusting the camera. Set up the tripod at a distance from the object you wish to photograph such that this object subtends the proper visual angle—30–60 degrees. Bring it as nearly as possible on a level with the middle

point of the object, and level it by adjusting the legs. Focus the object roughly on the ground glass, by drawing out the latter. Raise or lower the lens, by sliding the front of the camera, until the middle of the image comes into the middle of the glass. Do not tip the camera, if you can avoid it, to bring this result about; and in any case keep the ground glass vertical. If the image of the object is too small, bring the camera nearer; if too large, move the camera farther off, and readjust as before.

IV. ACCURATE FOCUSSING. In accurate focussing, use the largest aperture. If the edges of portions of the image are colored, adjust so that they may be red, rather than blue. If you cannot focus exactly, pull the camera out a little too far, then push it in a little too far, so as to produce equal indistinctness in both cases, then set it half-way between these limits.

V. TESTING A PLATE. Focus the camera as in IV. upon a brick wall, in shadow. Remove the ground glass, and set the plate-holder in its place. Use the smallest aperture for this process. Cap the lens, and pull out the slide so as to expose about one twelfth of the plate. Remove the cap, and expose the plate 16 minutes.

Draw out the slide so as to expose another twelfth of the plate 8 minutes. Make successive additional exposures, of successive additional twelfths of the plate as follows: 4 min., 2 min., 1 min., 30 sec., 16 sec., 8 sec., 4 sec.. 2 sec., 1 sec., and again 1 sec. Immediately cap the lens, and close the slide. Take the plate-holder to the dark room.

VI. PREPARING THE OXALATE DEVELOPER AND FIXING SOLUTION. Make a solution of 10 grams of ferrous sulphate in 30 grams of water.

Make another solution of 30 grams of potassic oxalate in 90 grams of water. (It is well to add from 1 to 2 grams of potassic bromide to this solution).

Make a third solution of 15 grams of hyposulphite of sodium in 60 grams of water. This is called the fixing solution. Pour it into a glass tray especially devoted to this purpose, and make sure that it is in the dark room before beginning to develop.

VII. Trying the developer. Mix half of your iron solution (20 g.) with half of your oxalate solution (60 g.) in a developing tray, in the dark room, and exclude all but red light as in II.

Take the plate out of the plate-holder, and cut it into five strips, lengthwise, by means of a diamond. Immerse one of the strips in the developing solution. Rock the developer for 8 minutes.

Then immerse another strip with the first for 4 minutes; then still another for 2 minutes; then another for 1 minute, and finally all five strips for 1 minute.

When the last minute is up, immediately flood the strips with water from the faucet, and after they have been washed a minute, place them in the hyposulphite solution.

VIII. Fixing images. Leave the strips in the "fixing" (hyposulphite) solution until the edges become clear. The door may now be opened. Wash the strips 15 minutes under the faucet.

IX. Interpreting results. Hold up the strips to the light. Sixty areas should now be visible, that is 12 areas on each of the five strips, due to different degrees of exposure. Which of these areas shows the best image of the bricks? How long was this area exposed? How long was it developed? (Add all the separate times concerned). What is the best time for exposure? for development? Note that the method employed enables you to find this out for yourself with any kind of plate, any lens, any aperture, any illumination, and any developer by sacrificing a single plate.

X. Make a negative with the information obtained.

30. PHOTOGRAPHIC PRINTING.

Apparatus: A printing frame; a sheet of platinotype paper; two trays; developing or toning solution; fixing solution; also a sponge; some smooth (not porous) paper, a pestle and mortar, some citrate of iron and ammonia, and some red prussiate of potash. Access to a moderately dark room.

I. Prepare some "blue-print" paper as follows: to 1 gram citrate of iron and ammonia add 1 gram red prussiate of potash; pulverize together in a mortar, add 10 grams of water in the dark, and stir thoroughly. Wet a small sponge, wring it out dry, and dip it in the mortar containing the mixture. Lay a sheet of waste paper on the floor, and on it a sheet of white paper to be sensitized. Run over the whole surface rapidly with the sponge in strokes first lengthwise, then breadthwise with respect to the paper. Hang the paper up in a dark place to dry for at least 15 minutes, or better one hour before using. Meanwhile proceed with the following experiments.

II. Put a piece of "platinotype" paper under the negative obtained in Exp. 29, or under some other negative; clamp it in the printing frame, and expose it to the light of the sun until the paper begins to darken in spots where the negative does not protect it.

To examine the print, take it into the dark room, or into the shade, and lift up one side only of the printing frame, so that the print will go back into place.

About 5 minutes will be required in full sunlight; about 20 minutes in skylight, and about 2 hours in a cloudy day.

III. When the print is dimly visible, remove it (in the dark room) from its frame; and cover it, in a developing

tray, with a nearly saturated solution of oxalate of potash, called the "developing solution".

When the print is fully developed (darkened), "fix" it by soaking it in a solution of one part hydrochloric acid in 100 parts of water, called the "fixing solution". Then wash it in pure water, and dry it.

IV. Now make a print on the blue-print paper which you have prepared. This should be exposed about 4 times as long as the platinotype paper. The print does not need to be developed, but must be fixed. This is done by soaking it in pure water for about 5 minutes.

If time remains, ask instructions for toning your blue-print, or for making prints by other processes.

31. DRAWING SPECTRA.

APPARATUS: A spectroscope; Bunsen burner; platinum wires; specimens of salts, and colored glasses.

I. Light a Bunsen flame, place it EXACTLY in front of the slit of the spectroscope, and hold a wire, dipped into a salt of sodium, in the lower part of the flame.

Turn the telescope (if necessary) until the yellow band due to sodium appears; and focus the telescope upon this band. Narrow the slit as much as may be practicable without showing irregularities in the illumination.

Bring the scale in focus by its own motion, without disturbing the focus of the telescope upon the slit. Then slide the scale by the screw or screws intended for this purpose, until No. 5 (or 50) of the scale comes opposite the sodium band.

Draw a scale 6 inches long, representing the scale of the spectroscope, and opposite the 5 (or 50) of this scale draw a vertical line, about half an inch long, to represent the sodium band. Note, in the drawing, the color of the band; also the color of the Bunsen flame. If there are any other bands, draw them also and note their colors.

II. Draw as in I. the spectrum of a Potassium salt, of a Calcium salt, of a Strontium salt, of a Barium salt, of a Lithium salt, and of Boracic acid.

III. Draw the spectrum of a luminous flame, also of a luminous flame seen through red glass, through yellow glass, through green glass, and through blue glass. State whether your pencil marks indicate dark or bright spaces in the spectrum.

32. DIFFRACTION.

Apparatus: A telescope with a piece of silk over the object glass; access to two distant lamps; a metre rod; a thread counter.

I. Place the lamp-flames at the height of the eye, turn them so as to be seen edgewise from a distance, and set them about 11 cm. apart; the line joining the flames being at right-angles with the line of sight.

Cover up one of the lights. Draw the diffraction effects seen through a handkerchief without any telescope at a distance of about 11 metres from the light.

Does the angular separation of the diffraction fringes depend upon the distance of the handkerchief from the eye?

State reasons for, or against, the supposition that the effects are due to light transmitted directly through meshes in the handkerchief.

II. Repeat I. with a piece of fine silk. Count the threads in a half-cm. of the silk, and compare with the handkerchief in I. Compare also the angular separation of the diffraction images in I. and II.

Does a fine or a coarse mesh produce the wider separation of the side images?

III. Light both flames, carefully measure the distance between them perpendicular to the line of sight, and stand off from the flames until their direct images, as seen through the telescope and silk cloth, are separated by three fringes, the central one nearly colorless, formed by the overlapping of the diffraction images of the flames.

Drop a plumb-line from the silk cloth to the floor, also from a point between the two flames to the floor, and find the distance between these two plumb-lines.

Find the ratio of the distance between the candles to

the distance between the plumb-lines, and note that this is approximately equal to the (small) angle subtended by the flames at any point in the handkerchief. Divide this angle by four to find the angle subtended between sucessive fringes at the same point.

Multiply the distance between threads of the silk cloth by the sine of the angle between successive fringes to find the mean wave-length of the light utilized in this experiment. (The sine of a small angle is practically equal to the angle itself.)

IV. Repeat III. at such a distance from the lamps as to make the central image reddish in the middle, and greenish on either side. The result should agree approximately with the wave-length of red light.

V. Repeat III. at such a distance from the lamps as to make the central image greenish or bluish in the middle, and reddish on the edges. The result should agree with the wave-length of green or blue light.

VI. Repeat III., IV., and V., if time permits, at such a distance that the space between the direct images is divided into 2 or 3, instead of 4 parts.

33. CHLADNI'S FIGURES, ETC.

Apparatus: A square and a round brass plate; a vice for clamping the same at the centre; a bow (with resin); some lycopodium and sand;—a steel spring; a steel or brass rod; and two wooden knife-edges for supporting the latter.

I. Scatter sand lightly over the square plate, touch it at the corners, and draw the bow vertically across the middle of one side, as slowly as is consistent with the production of a musical note. Draw the figure formed by the sand.

II. Repeat I. with two points damped between the bow and the corners of the plate, and with a somewhat more rapid motion of the bow.

III. Repeat I. damping the middle of each side and bowing the plate near one corner.

IV. Repeat III. with a somewhat more rapid motion of the bow.

V. See what other figures you can produce. Place your fingers where you want a nodal line to reach the edge of the plate, and bow the plate where you want to destroy a nodal line.

VI. Scatter a little lycopodium over the plate. Does the lycopodium collect where the sand collects? if not where is it gathered?

VII. Substitute a round plate for a square plate. Damp it at points 90° apart, and bow between these points. Draw the figure formed by the sand.

VIII. Repeat VII. with points 60° apart.

IX. Repeat VII. with points 45° apart.

X. Repeat VII. with points 36° apart.

XI. Repeat VII. with points 30° apart, etc., etc.

XII. See as in V. what other figures you can produce with the round plate. Also, test the behavior of lycopodium.

Can the plate be made to divide itself into an ODD number of vibrating sectors?

XIII. Where must the steel rod be supported in order that it may ring for a long time when struck? Where are the "nodes" in this case?

XIV. Clamp the steel spring at one end; force it to vibrate (with the fingers) at a rate much more rapid than its natural rate of vibration. Note the location of any point (or points) of minimum vibration which you may discover in this way. What are such points called?

Does pitch or rate of vibration increase or diminish, throughout your experiments, with an increase in the number of nodes or nodal lines?

34. NODES OF STRINGS AND PIPES.

APPARATUS: A large fork, electrically maintained in vibration; a thread and weight attached to fork; a metre rod; a V-shape slot and support; a resonance tube with siphon attachment; a jar of water; two tuning-forks (440 and 570); rubber rings.

I. (MELDE'S experiment). Set the large fork in vibration, and adjust the weight hanging from it by a white thread (if it is necessary to adjust it) so that the thread may be thrown in vibration attaining an amplitude of at least one cm. in certain places.

Draw the string as it now appears. What name is given to the points of minimum vibration?

Measure the distance of each node from the lower end of the string.

II. Find the effect of damping the string at each of the nodes by a V-shaped slot. Is the amplitude of vibration between the damper and the fork increased or diminished?

III. Find the effect of damping a string at any point between two nodes.

IV. Run down the string with the damper, and note the points of maximum and minimum vibration. How do these points compare with the nodes and antinodes?

V. Increase the weight on the string by 10 or 20 per cent. What is the effect of a slight change of tension on the power of a string to respond to a given rate of vibration?

VI. Run down the string with the damper, as in IV., when it is loaded as in V. What is the effect of a slight increase of tension on the lengths responding to a given fork?

VII. Set the resonance tube on the floor, and raise the jar of water connected with it. As the water flows into the

tube, hold a vibrating violin A-fork over the open mouth of the tube. Mark, by rubber rings, the water levels causing the note of the fork to swell out.

Confirm these results as the water flows out of the tube into the jar, lowered for this purpose. Adjust the rings accurately by causing the water level to pass by them first in one direction, then in the other direction.

Make a diagram showing the spacing of the rings, with actual measurements.

Assuming that the points where the vibration of a column of air can be cut off without prejudice to its rate of vibration correspond to nodes, as in the case of strings, where are the nodes in a pipe stopped at one end?

VIII. Repeat VII., if time permits, with a treble C-fork, instead of a violin A-fork. How do the distances between nodes compare?

IX. Find the difference, if any, between the depths of water in a large and in a small hydrometer jar responding to a given fork, and give the dimensions of each jar.

35. VIBRATION OF RODS.

APPARATUS: A vice; a clock-spring; a set of tuning forks; a rubber hammer, and access to a clock.

Strike the tuning forks only with the rubber hammer, so as to avoid injury.

I. Straighten the clock-spring, and clamp it in the vice so as to stand out horizontally. To do this, the plane of the spring must be vertical. Increase or diminish the length of the free portion of the spring until, when set in vibration, it keeps time with the clock; making one vibration from side to side and back again in one second. Note that this is called a COMPLETE VIBRATION in acoustics. Measure the length of the projecting portion.

II. Change the length of the free part of the spring until it vibrates four times as fast as before. Again measure the length of the projecting portion.

Assuming that the time of vibration is proportional to some power of the length of a spring, what is the power in question?

III. Repeat I. or II. with some new length, chosen so as to verify, or disprove, the conclusion in II. Is this conclusion verified or not?

IV. Test the vibration of the spring for a series of decreasing lengths, and describe what you see or hear.

In what respect do vibrations which you can see and count differ from those which affect the ear?

V. Adjust the length of the spring until the note which it emits when set in vibration agrees in pitch with the largest tuning fork in your set. Measure the length of the free part of the spring.

Calculate the pitch of the spring in complete vibrations per second, making use of the law obtained in II.

(If you cannot tell when the pitch of the spring is the same as that of the fork, ask for help).

VI. Find as in V. the pitch of each of the forks in the set.

VII. Find the effect of sounding two forks of nearly the same pitch at the same time. Express this quantitatively, if possible.

VIII. Find the effect of loading each of the forks in VII. with a small quantity of wax.

36. LISSAJOUS' CURVES.

Apparatus: A Blackburn's pendulum, a set of rectangular rods forming Lissajous' curves; access to a clock.

I. Adjust the Blackburn's pendulum in the shape of a T; fill the tracer with sand; draw it out diagonally, then release it, and let it trace a complete cycle of curves on a piece of paper.

Draw some of the more characteristic curves traced by the pendulum.

Find the rate of vibration of the pendulum in a direction parallel to the plane of the T, and also in a direction at right angles with this plane. How do these rates compare?

II. Adjust the Blackburn's pendulum in the shape of a Y, with the stem of the Y one fourth of the maximum radius of vibration. In other respects, repeat I.

Why are the rates of vibration in perpendicular planes now very unequal?

III. Obtain as in I. and II. drawings of curves representing a variety of simple integral ratios between the two rates of vibration of the pendulum. (The most important ratios are 1:1, 2:1, 3:1, 3:2, 4:3, etc.)

IV. Pull each of the rods diagonally, and draw the various curves to which they give rise, in so far as it is possible to recognize these curves.

In connection with the drawings of the curves, note whether the figures are persistent in form, or whether they pass through a series of forms. In the latter case, give some idea of the succession of forms, and whether this succession is slow or rapid.

Point out every possible case of resemblance between the curves made by the rods and those drawn by the pendulum.

Assuming that the curves formed by the rods are due, like those drawn by the pendulum, to the composition of two vibrations at right-angles, what do you infer to be the ratio between the two rates of vibration in each case which you have recognized?

37. LAWS OF STRINGS AND PIPES.

Apparatus: A sonometer with pulley (or other means of stretching a wire); 2 wires 4 ft. long, of different weights; a sliding bridge; a metre scale; weights from 1 to 4 kilograms; a set of organ-pipes (or other means of producing the musical scale); also trip scales and weights.

I. Stretch the lighter wire with the lightest weight —about 1 kilo.—and move the bridge until the note emitted by the wire when plucked is in unison with "Ut 3" of the organ-pipe. Measure the length of the string under vibration, also the depth of the pipe.

II. Repeat I. with about 4 times the weight stretching the string. If the length of the string is proportional, directly or inversely, to some power of the weight stretching it, what is the power in question?

III. Repeat II. with a series of organ-pipe notes covering an octave. What relation exists between the lengths of the string and the depths of the pipe.

Assume that the rates of vibration of the different notes are proportional to the following numbers:
Ut, 24; Re, 27; Mi, 30; Fa, 32; Sol, 36; La, 40; Si, 45; Ut, 48: find the product of each of these numbers by the corresponding length of the string. State the law connecting the length of a string with its rate of vibration.

Find in the same way the law connecting the length of an organ-pipe with its rate of vibration.

IV. Weigh the string used in II., also weigh the other string. Repeat II. with the heavier string.

If the length of a string emitting a given note is directly or inversely proportional to some power of the weight of the string, what is the power in question?

Summarize your results as follows:—The rate of vibration of a string is proportional directly or inversely to the xth power (or root) of its length, directly or inversely to the yth power (or root) of its tension, and directly or inversely to the zth power (or root) of its weight per unit of length.

38. GRAPHICAL MEASUREMENT OF PITCH.

Apparatus: A tracing apparatus; a rubber hammer; a glass slide; powder, and access to a clock.

I. Bend the styles attached to the fork and to the pendulum of the tracing apparatus, so that each may graze lightly the surface of a piece of glass. Powder the glass with chalk, and set the pendulum in vibration by drawing it about one inch to one side and releasing it, and set the fork in vibration with a sharp blow of a rubber hammer. Without loss of time, draw the glass under the tracing apparatus at the rate of about one foot per second.

Repeat until both the fork and the pendulum have made simultaneous markings upon the powdered glass. The pendulum should have registered at least two complete vibrations.

Measure the distance between the two styles, and lay off an equal distance on one side of each mark made by the pendulum to show points where the pendulum WOULD HAVE MARKED if the style attached to it had absolutely coincided with that attached to the fork. Mark these points a, b, c, d, etc.

Count the number of complete waves traced by the fork between a and b, b and c, c and d, etc. Estimate halves, and if possible quarters of complete vibrations in each case.

Time 100 or, if possible, 200 complete vibrations of the pendulum.

Are the numbers of complete vibrations between a and b, b and c, c and d, etc., equal or alternately greater or less? How do the numbers of vibrations between alternate marks, such as a and c, b and d, etc., compare? Why do you prefer to base calculations upon the number of vibrations registered

between alternate marks? Why does not irregularity in the speed of the glass affect the results?

Calculate the number of complete vibrations made by the fork in one second. What name is given to this quantity?

II. Repeat this experiment from the beginning until concordant results are obtained. Find out whether the arc of oscillation of the pendulum has any appreciable effect upon its rate of vibration, and whether the amplitude of the tuning fork affects the results.

39. BREAKING STRENGTH.

APPARATUS: A spring balance of 30 lbs. capacity; standard weights for testing the same; two bobbins, one fixed, the other attached to the hook of the balance; several lengths of wire about one metre each; a metre rod; access to scales with weights to 0.1 gram; access to screw gauge.

I. Find the reading of a spring balance, when unloaded, both in a vertical and in a horizontal position.

Does the spring balance read the same in these two positions and why?

How should the spring balance be held to avoid corrections from this source?

II. Test the spring balance by hanging weights on it—say 10, 20, and 30 lbs. Within what probable limits can the balance be assumed to be accurate?

III. Cut off a metre of fine copper wire (No. 31, B.W.G.), and weigh it to 0.1 gram.

Find the diameter of the wire, by a screw gauge, within 0.001 cm. Ask for instructions if necessary in the use of the gauge.

Fasten one end of the wire to a fixed bobbin, and wind most of it round the bobbin. Fasten the other end of the wire to a spring balance, and take one or two turns round a bobbin attached to the hook of the balance.

Apply a steadily increasing force to the wire. Notice the indication of the spring balance when the wire begins to stretch, also when the wire breaks. TAKE CARE that the hand is held so as not to be injured by the recoil of the spring.

Measure the diameter of the wire near the break.

Repeat until tolerably concordant results are obtained.

IV. Repeat III. with a brass or steel wire of as nearly as possible the same diameter.

V. Repeat IV. with a wire of the same material, but of either twice the cross-section, or twice the diameter.

VI. Answer the following questions:—

1. How do the different wires experimented with compare in respect to stretching before breaking? and as to the contraction of their diameter near the break?

2. Find the relative breaking strength of wires of at least two different materials, having the same cross-section.

3. Calculate the length of each wire which would break under its own weight.

Why should the last result be the same for any two wires of the same material?

4. Find the cross-section of each wire (by multiplying the square of its diameter by 0.7854), and calculate the force in metric "tonnes" (1000 kilos.=2205 lbs. to the "tonne") necessary to break a wire of the same material one sq. cm. in cross-section, assuming that the breaking strength is proportional to the cross-section.

40. STRETCHING WIRES.

Apparatus: A 30-lb. spring balance; a metre rod divided into millimetres; considerable lengths (from 4 to 10 metres) of wires of different diameters and materials; screw hooks for fastening the same; access to a screw gauge.

I. Fasten one end of a small wire to a screw hook (or vice), the other end to the hook of a 30-lb. spring balance. Bend the loose end of the wire near the spring balance at right angles with the main portion of the wire, so as to form an index, by which the elongations of the wire are to be read. Fix a scale of millimetres so as to measure the elongations in question.

Straighten the wire by a strain of two or three pounds, and gradually increase the force until the index comes exactly opposite one of the mm. divisions on the scale. Note this mm. division, also the reading of the spring balance.

Again increase the force until the wire stretches another mm. Note the reading of the index on the mm. scale, and that of the spring balance as before.

Continue in this way until the force reaches one third the breaking strength of the wire, or if this be unknown, until the wire has stretched one thousandth part of its length. Do not apply greater forces, for fear of exceeding the limits of perfect elasticity of the wire.

Repeat until concordant results are obtained. Always record the WHOLE readings, thus :

Index	653 mm.	Force	3.5 lbs.
"	654 mm.	"	5.7 lbs.
	etc.		etc.

Do not record the DIFFERENCES between successive readings, e. g. "1 mm., 2.2 lbs." The former method contains all the information that the latter contains, and more.

II. Repeat I. with an index attached to the middle of the wire, so that the stretching of only half is measured.

III. Repeat I. with a larger wire of the same material and length.

IV. Repeat I. with a wire of as nearly as possible the same length and diameter, but of different material (e. g. copper).

V. Substitute in IV., if time permits, other wires of different materials.

VI. Find the length of all the wires subject to stretching, by the metre scale; also the diameter of these wires, as in Experiment 9, by a screw gauge.

1. How does the increase of force compare in general with the increase of stretching? Why is it necessary to begin with a certain force in order that regularity in this comparison may appear? Why is it unnecessary to apply a correction for the position of the spring balance?

2. How does the force required to produce a given amount of stretching vary with the length subject to stretching?

3. How does the force required to produce a given amount of stretching vary with the diameter of the wire? with the cross-section of the wire?

4. Find the force in grams (453.6 grams to the lb. Avoirdupois) which would double the length of a wire 1 sq. cm. in cross-section, provided that rupture did not take place. Note that this is called "Young's modulus of elasticity." Is Young's modulus the same for all materials?

41. BENDING BEAMS.

Apparatus: Two knife-edges; a scale-pan with suspending cord; three beams, more than one metre long, 1 by 1, 1 by 2, and 2 by 2 cm.; two weights, 500 g. and 1000 g.; a metre rod.

I. Support a wooden beam, one cm. square, on two knife-edges, 100 cm. apart; hang a scale-pan from the middle of the beam, by a cord passing through a hole in the table; and note the height of the middle of the beam above the table, as measured by a vertical scale of mm. sighted across the upper surface of the beam.

Place a 500-gram weight in the pan, and again determine the height of the beam. How much has the beam been deflected by the weight?

II. Repeat I. with 1000-gram weight. How does the deflection due to 1000 grams compare with that due to 500 grams?

III. Find as in I. the deflection due to 1500 grams.—Find by comparison of the weights and deflections in I., II., and III., the simplest possible law connecting the deflection with the weight, within the limits of errors of observation.

IV. Repeat III. with a beam 1 cm. by 2 cm. in cross-section, laid flatwise on the supports. How does the breadth of the beam in IV., compare with that in III.? How do the lengths, depths, and weights compare in III, and IV.? What is the effect of doubling the breadth of the beam on the deflection produced?

V. Repeat IV. with the beam edgewise. What is the effect of doubling the depth of the beam on the deflection produced?

VI. Repeat V. with a beam 2 cm. by 2 cm. Find by

comparison of the results in V. and VI. the effect of doubling the breadth of a beam, 2 cm. deep. Find by comparison of the results in IV. and VI. the effect of doubling the depth of a beam 2 cm. broad. Find by comparison of III. and VI. the effect of doubling the diameter of a square beam.

How do your inferences in VI. as to the effects of doubling the breadth and depth of a beam compare with those in IV. and V.? Assuming that the deflection of a beam is proportional directly or inversely to some power of the breadth, to some power of the depth, and to some power of the mean diameter (if the shape of the cross-section is constant), what are the powers in question?

VII. Repeat III. with a distance of 50 cm. instead of 100 cm. between the supports. If the deflection of a beam is proportional to some integral power of its length, what is the power in question?

State the laws connecting the deflection of a beam with its length, breadth, depth, and load suggested by your experiments.

Express the load upon a beam in terms of some constant multiplied by integral powers of the length, breadth, depth, and deflection of the beam, assuming the laws above to be true.

42. TWISTING RODS.

Apparatus: A single piece for from 2 to 4 students, consisting of the following parts: 2 beams, 1 by 1 and 2 by 2 cm., respectively, each 115 cm. long; a clamp (with spirit level) joining the beams together horizontally; two sockets with cardboard circles for the free ends; centres to support the same; 4 bobbins, 5 cm. long, 5 cm. diameter, fitting the rods; 4 spring balances (4 lbs. by oz.); jacks on rollers to support spring balances horizontally; cords to connect balances with bobbins; and means of shortening the same. A metre rod, and access to a vernier gauge.

I. Attach one pair of spring balances to the middle bobbin on the small beam, the other pair to the middle bobbin of the larger beam; but put no strain on them. See if the circles both read zero when the clamp is leveled. If not, note the reading of each circle.

Tighten one of the cords until the spring balances read 64 oz. Why do all the spring balances give the same reading?

Readjust the level on the clamp, and note the angle of twist in each beam. If the twist is proportional, directly or inversely, to some power of the diameter, what is the power in question?

II. Repeat I. with the balances attached to the outer bobbin in each case.

How does the twist of a beam compare with the length subject to torsion?

III. Repeat II. with forces of 32 oz. instead of 64 oz. How does the twist of a beam compare with the forces applied to it under given conditions?

In what respects do the laws of torsion correspond with

the laws of stretching, and in what respects do the ycorrespond with laws of bending?

State a general law (Hooke's law) connecting force with the displacement produced (whether longitudinal, transverse, or torsional). See Exps. 40—42.

Show that the relation between the length of a beam, subject to stretching or torsion, and the angle of torsion produced could be anticipated by arithmetical considerations.

43. COUPLES.

Apparatus: A torsion apparatus; a screw-driver; 2 spring balances, (4 lbs. by oz.); strings and screw-eyes for attaching the same; a metre rod.

I. Read the disc of the torsion apparatus by two nails on opposite sides of the disc. Place one of the movable pegs opposite the point *i*, of the disc, and connect it, by means of a spring balance and cords, to a screw-eye at *j*. Place the other peg similarly opposite *j*, and connect it, by the other spring balance, with the screw-eye at *i*. Tighten the cords by twisting the pegs equally, until each spring balance reads 36 ounces. Slide the pegs until the cords are at right-angles with *ij*, and readjust the tension to 36 ounces. Read the disc by means of the two fixed nails. Measure the perpendicular distance between the cords. Note whether the disc is deflected bodily, or only twisted about its centre.

II. Repeat I. with *d* and *e* substituted for *i* and *j*.

III. Repeat II. with *b* substituted for *e*, but with forces unchanged in direction, and hence at right-angles with *c e*, (not *b d*).

IV. Repeat II. with *a* and *b* substituted for *d* and *e*, and forces unchanged in direction, that is, at right-angles with *a b* or *c e*.

V. Repeat II. with *c* and *d* substituted for *d* and *e*, and forces unchanged in general direction, that is, at right-angles with *c d*.

VI. Repeat II. with 12 ounces for 36 ounces, and *c* and *f* for *d* and *e*.

VII. Repeat VI. with *c* and *e* for *c* and *f*.

VIII. Repeat VI. with *d* and *e* for *c* and *f*.

IX. Tabulate results as follows: column 1, numbers corresponding to parts I.—VIII. of this experiment; column 2, forces in ounces applied; column 3, perpendicular distances between cords; column 4, products of numbers in columns 2

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and 3; column 5, deflections in cm. produced; column 6, ratios of numbers in columns 4 and 5.

Answer the following questions:

1. What is the effect of rotating a "couple" from the symmetrical position, *i j*, in I., through a certain angle, (90°) into another symmetrical position, *d e* in II., the magnitude of the forces and perpendicular distance between the cords remaining the same?

2. What is the effect of changing the point of application of one of the forces from *e* in II., to *b* in III., the lines of action of the forces, and hence the perpendicular distance between them, remaining unchanged?

3. What is the effect of moving a "couple" from the symmetrical position, *d e*, in II., in a direction at right-angles to *d e*, into the unsymmetrical position, *a b*, in IV.?

4. What is the effect of moving a "couple" from the symmetrical position, *d e*, in II., in a direction parallel to *d e*, into the unsymmetrical position, *c d*, in V.?

5. What in general would you infer to be the effect of moving a "couple" from one place to another without changing the magnitude of the forces or the perpendicular distance between their lines of a action?

6. What is the effect of increasing the perpendicular distance between the lines of action of two forces, constituting a "couple," from 9 cm. in II., to 27 cm. in VI., provided that the forces are diminished in the same proportion, so that the product of the forces and the perpendicular distances between their lines of action remains the same?

7. What is the effect of varying the perpendicular distance between the lines of action of two constant forces constituting a "couple" on the angle of twist produced? (See VI., VII., VIII.)

8. What is the effect of changing the force from 36 oz. in II. to 12 oz. in VIII.?

9. Name all the circumstances discovered in this and in the last experiment which may modify the angle of torsion produced in a rod of *given length and diameter*.

10. Upon what product does the effect of a couple depend?

44. COMPOSITION OF FORCES.

APPARATUS: A blackboard; two 30–lb. spring balances, hooks for supporting the same; 6 metres of strong cord; a weight over 30 lbs; a lever; a metre rod; and chalk.

I. Suspend a horizontal lever by means of two vertical cords attached to two spring balances, hung upon stout nails or hooks at the proper distance. Read the spring balances. Attach the weight by a cord between the middle and end of the lever, and again read the spring balances. Measure the distances between the middle cord and the extreme cords.

Answer the following questions:

1. What two couples, introduced by the suspension of the weight, are in equilibrium?

2. What relation exists between the increase in the reading of each spring balance and the distance of its cord from the middle cord? and why?

3. What is the magnitude of the weight (that is, how many pounds does it weigh)? Give reasons in full for this answer.

II. Repeat I. with the weight suspended at the centre of the lever. Answer questions 1, 2, and 3, under I.

III. Hang up two spring balances of 30 lbs. capacity on two nails above a blackboard, at a distance of about one metre. Connect these by a cord a little over a metre in length. From the middle of the cord, suspend a weight of a little over 30 lbs. Draw lines on the blackboard parallel to the three sections of the cord. Measure off, on two of these lines, distances in inches numerically equal to the respective forces in lbs. indicated by the spring balances acting along these lines. Complete the parallelogram with these distances as sides. Draw the diagonal of this paral-

lelogram, and measure it in inches. Answer the following questions:

1. What relation exists between the direction of the diagonal and that of the cord supporting the weight? and why?

2. What relation exists between the sides of the parallelogram? and why?

3. What is the magnitude of the weight, and why?

IV. Move the point of attachment of the weight so as to be nearer one spring balance than the other, then proceed as in III. Answer questions 1, 2, and 3, under III.

V. Hang up the weight by a long cord from one of the nails. Lay a scale of inches horizontally on the ledge of the blackboard. Pull the weight sideways (horizontally) by means of a spring balance, until the deflection of the suspending cord, measured by the scale, amounts to one foot; then read the spring balance. Measure the vertical distance from the nail to the scale.

Calculate the weight by the triangle of forces.

VI. Repeat V. with a deflection of 2 feet instead of 1 ft. Calculate the weight as in V.

VII. Make a table showing the different estimates of weight in I.—VI., and answer the following questions:

1. Why could not the weight be directly measured by suspension from a single one of the spring balances?

2. How do you explain the differences between your different estimates of the weight?

3. What are your inferences as to the relative accuracy and utility of the different methods employed for the estimation of weight by the composition of forces?

45. FALLING BODIES.

Apparatus: A falling bodies' apparatus, with ball, thread, carbon paper and matches; trip scales with weights to 1 gram, and a spring balance, graduated in decimal multiples of a dyne.

I. Attach a strip of white paper, and over it, a strip of carbon paper, near the lower end of a pendulum rod, and hang up a ball by a thread passing over a peg above the rod, so that the ball may hang opposite the papers. Slide the support of the pendulum rod, if necessary, so as to graze the ball when at rest.

Raise the ball, by the thread, to a mark near the top of the pendulum rod; pass the thread around the three pegs, and fasten it to a screw-eye in the pendulum rod. Adjust the length of the thread so that the pendulum may be deflected ten or twenty degrees, while the ball hangs opposite the mark near the top of the rod. Be sure that the ball and pendulum are about in equilibrium, so that a slight jar may not disturb the adjustment.

Stop all oscillation of the ball, and burn the thread between the two upper pegs. The ball in falling should strike the strips of paper, and make a mark on the white paper. Readjust the papers, if necessary, until this result is attained.

Measure the distance between the mark at the top of the pendulum rod, where the ball began to fall, and that made by the ball on the white paper. Repeat until two or three concordant results are obtained. (They should not differ by more than 1 cm.)

Find the time of the pendulum, by observations of 100

complete oscillations;* and calculate the time occupied in reaching the middle point of the first half-swing, where the ball and pendulum meet.

What is the distance fallen in the given time? What is the mean velocity during this time? What is the final velocity? (This may be assumed to be twice the mean velocity, since the initial velocity is zero).

II. Repeat I. with one or more pendulum rods of different lengths.

Answer the following questions:

1. If the distance through which a body falls in a given time is proportional to some integral power of this time, what is the power in question?

2. If the average velocity of a falling body is proportional to some integral power of the time of fall, what is the power in question?

3. Show that your answers to (1) and (2) are consistent, remembering that the distance traversed by any moving body in a given time is equal to the product of that time and the average velocity.

4. If the final velocity of a falling body (originally at rest) is always twice its average velocity, what law connects the final velocity with the time of fall?

5. What velocity would the body experimented upon acquire in ONE SECOND, assuming the law in (4) to be true?

6. How do bodies differing in mass or in material compare in regard to the velocity which they acquire in a given time under the action of the earth's gravity, when frictional forces, due to the air or other causes, can be neglected? (Ask, if necessary, for directions enabling you to answer this question experimentally).

III. Find by a balance the weight in grams (or mass) of the falling body. Find also by means of a spring balance, as in Exp. 1, its weight in dynes.

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* A "complete oscillation" of a pendulum consists of two swings in opposite directions; one from the farthest left-hand point to the farthest right-hand point, the other from the farthest right-hand point back again to the farthest left-hand point. The "time" of a pendulum is that occupied by a single swing in either direction—that is, by one half of a complete oscillation.

Multiply the mass of the falling body by the velocity which it acquires in one second. (See (5) under II.) How does this product compare with its weight in dynes?

Assuming that the weight of a body in dynes is numerically equal to the product of its mass and velocity acquired per unit of time under the action of gravity, what is the WEIGHT OF ONE GRAM IN DYNES? Compare this result with that obtained in Exp. 1.

46. MAGNETIC ATTRACTIONS AND REPULSIONS.

Apparatus: Three magnets, about 15 × 1.2 × .6 cm.; 2 unmagnetized bars of the same dimensions; a balance sensitive to 1cg.; a set of dyne-weights; lead shot for counterpoising; a stand to hold a magnet; a metre rod.

Note. The magnets are supposed to be horizontal and to lie flatwise throughout these experiments.

I. Place magnet No. 3 on the balance pan; counterpoise it, and raise the balance beam by its lever, so that the magnet may swing freely.

Find whether the poles of two other magnets marked "N" attract or repel that of the suspended magnet marked in the same way, when held at a short distance (2 or 3 cm.) from it; find also how they act upon the pole marked "S"; find also how the poles marked "S" act upon each pole of the suspended magnet.

Which poles of the two magnets not suspended are similar, and which dissimilar, in respect to their action upon the poles of the suspended magnet?

II. Find whether two poles found in I. to be similar attract or repel each other; also whether two dissimilar poles attract or repel each other.

III. Counterpoise magnet No. 1 on the balance, and clamp magnet No. 2 so that one of its poles may be directly above the similar pole of No. 1. Make the distance between the axes of the magnets exactly 2 cm. when the balance beam is raised and horizontal. Slide the stand, to which magnet No. 2 is clamped, over the table, so as to change the distance by which the two poles overlap WITHOUT CHANGING THE DISTANCE BETWEEN THE AXES OF THE MAG-

NETS. Find a position, in this way, in which a maximum repulsion is obtained.

Assuming that the poles of the two magnets are similarly situated, and that their mutual repulsion is some function of the distance between them, where are these poles located? Multiply experiments until you feel sure of your answer.

IV. Measure the force in dynes with which a single pair of similar poles repel each other under the conditions of III. Do this by the use of dyne-weights (i. e. weights so adjusted that the force in dynes exerted by gravity upon them at Berkeley is correctly indicated by the numbers stamped upon the weights).

V. Place the centre of magnet No. 2 directly above the centre of magnet No. 1, and at a distance of 2 cm. from it, as in III. Then rotate magnet No. 2 until a maximum of repulsion is observed.

Describe the relative position of the magnets and of their poles when this occurs.

VI. Make sure that the distance between the two magnets is still 2 cm. from centre to centre. Measure the force of repulsion between the two magnets as in IV., by the use of dyne-weights.

How does this compare with the force exerted in III. by a single pair of poles? and why?

VII. Repeat VI. with magnet No. 3 instead of No. 2.

VIII. Repeat VII. with magnet No. 2 instead of No. 1.

IX. Select from your three magnets a pair as nearly as possible equal in strength; set them up as in VI., VII., or VIII., only turn one of them end for end, so as to produce attraction instead of repulsion, and measure this attraction, at a mean distance of 2 cm. as before, by the use of dyne-weights.

Is the repulsion between two magnets at a given (small) distance equal to, greater than, or less than the attraction?

X. Take a bar of uumagnetized steel (make sure that it is unmagnetized, by proving that it has no attraction or repulsion for a similar bar), and measure the force in dynes

with which it attracts or is attracted by one of the steel magnets already employed, when held at a distance of 2 cm. from this magnet. Find, also, the effect of turning the magnet end for end.

Under what circumstances (if any) is a piece of unmagnetized steel repelled by a magnet?

What should you suppose to be the action between either of two magnets and the unmagnetized portion of the steel of which the other magnet is composed?

Account (quantitatively, if possible) for the difference between the attractive and repulsive forces of two magnets at a given distance.

XI. Repeat IX. with a distance of 1 cm. instead of 2 cm. between the centres of the magnets, so as to find the force of attraction with a distance of 1 cm. between each pair of poles. Then reverse one of the magnets, and find, as in VI., VII., or VIII., the force of repulsion under similar circumstances. Divide each of these results by 2, to find the force due to a single pair of poles. Average the two quotients to find the mean force (whether attractive or repulsive) between a single pair of poles at a distance of 1 cm.

Why is the so-called "inductive effect," studied in X., eliminated by thus taking an average?

Assuming that the mean force in dynes between the two poles in question, at the distance of 1 cm. (being equal in general to the product of the numbers of units of magnetism which they contain) is in this case (the poles being equal in strength) equal to the square of the number of units in each, calculate the strength of either pole in magnetic units.

XII. Calculate as in XI., from the results of VI.—IX., the mean attractive and repulsive force between a single pair of poles 2 cm. apart.

If the mutual attraction or repulsion of two poles varies, directly or inversely, according to some integral power of the distance between them, what is the power in question?

Find, if time permits, whether the law stated above seems

to hold for distances as great as 10 cm. When you have decided as to this fact, ask for an explanation.

NOTE. The calculations in XI. and XII. may be deferred, if necessary, to the beginning of Exp. 47, with which they are closely connected.

47. HORIZONTAL COMPONENT OF THE EARTH'S FIELD.

APPARATUS: A magnet tested in Exp. 46; a compass; a metre rod, and a pencil.

I. Draw a pencil line on the table in the direction indicated by a compass needle. Place a magnet, tested in Exp. 46, on this pencil line, near the compass. Which pole of the magnet must be nearer the compass in order to reverse it? How near must the end of the magnet be to the centre of the compass-needle in order that reversal may take place? in order that the compass may be barely able to recover its ordinary direction? in order that the compass may stand in neutral equilibrium?

II. Repeat I. with the magnet south of the compass.

III. Draw a pencil line on the table at right-angles with the ordinary direction of the compass, and lay the magnet on this line, east of the compass, and with the north pole to the east. In what direction is the compass deflected? How is this deflection affected by an increase or decrease in the distance of the magnet? At what distance, measured between the nearer end of the magnet and the centre of the needle, is the deflection 45 degrees?

IV. Repeat III. with the magnet turned end for end.

V. Repeat III. with the magnet west of the compass.

VI. Repeat III. with the magnet west of the compass and turned end for end.

VII. Answer the following questions:

1. Is your compass-needle constructed so as to be sensitive to horizontal, or to vertical forces, exerted upon the poles? Must these forces be parallel to, or at right-angles with, the axis of the needle; and must they act in the same

or in opposite directions upon the two poles in order to affect the needle?

2. Why is the direction indicated by the north (or north-seeking) end of a compass-needle the same as that of the horizontal component of the force which a magnetic north pole would experience if situated near the centre of the compass?

3. How can you find the direction of the horizontal component of the force exerted by the earth's magnetism upon a magnetic north pole? and by what pencil line upon the table is this direction represented?

4. Asuming that the force exerted by your magnet in I. and II. upon a magnetic north pole at the centre of the compass would be in equilibrium with the horizontal component of the earth's force upon the same pole, what must be the direction of the former? And how is this direction related to that of the axis of the magnet?

5. State the angular relation in III.—VI. between the resultant force upon either pole of the compass-needle, determining the deflection of this needle, and the (horizontal) components of this force due one to the magnet, the other to the earth; also the angular relation between these two components. What relation must exist between the magnitudes of these components in order that the angular relations above may exist?

6. How does the magnitude of the force exerted by your magnet in I. or II. upon either pole of the compass-needle compare with that exerted upon the same pole by the earth's magnetism? and why?

7. Why are the distances of the magnet from the compass approximately equal in I. and II.? in III.—VI.? How do the distances in I. and II. compare with those in III.—VI., and why?

8. What reason have you to think that the forces exerted by your magnet upon ANY magnetic pole, at the distance and in the relative position of I.—VI., would be equal in magnitude to that exerted upon the SAME POLE by the earth? Would these conclusions apply to a north pole of UNIT MAGNITUDE?

9. Where are the poles of your magnet? (See Exp. 46.) How far is the nearer pole, on the average, in I.—VI., from the centre of the compass-needle? What is the strength of this pole? (See Exp. 46.) What force in dynes would this nearer pole exert on a unit pole at the centre of the compass? (To find this, divide the strength of the pole by the square of its average distance).

Find in the same way the average force in dynes exerted by the farther pole upon a unit pole at the centre of the needle. Is this force in the same direction or in a direction opposite to that due to the nearer poles.

Find the resultant of the two forces calculated above. Should the two forces be added or subtracted?

What is the magnitude of the force in dynes which the earth would exert upon a unit magnetic pole?

10. Given that a magnetic field is any portion of space in which magnetic poles are subjected to forces, and that the strength of a magnetic field is measured by the force in dynes exerted upon a unit magnetic pole placed in the field in question, find the strength of (1) the magnetic field due to your magnet at a distance along its axis equal to that in I.—VI.; also (2) that due to the earth's magnetism. Why is the earth's magnetic field (approximately) the same at different points not very far apart? (Ask if you do not know.)

11. How many tenths of a unit of magnetism would act, at a distance of one centimetre, upon any magnetic pole (free to move horizontally) with a force equal to that exerted by the earth (at an enormously greater distance) upon the same magnetic pole?

12. Explain, with actual figures obtained from your observations, two significations which may be attached to the statement that the horizontal component of the earth's magnetic field is equal to —— tenths of a unit. (See 10 and 11.)

48. EARTH'S ACTION ON SUSPENDED MAGNET.

Apparatus: A bifilar suspension, a magnet tested in Exps. 46 and 47; a metre rod; a cardboard protractor; scales and weights to 1 gram; access to screw gauge.

I. Adjust a "bifilar" suspension (if necessary) so that its two threads are of equal length, parallel, and magnetically east and west of each other. Place the magnet, already tested in Exps. 46 and 47, on the suspended carriage, with its north pole toward the magnetic east. Note the deflection. Reverse the magnet, and again note the deflection. Find the mean deflection, in degrees.

II. Find the combined weight of the magnet and suspended carriage. (It is not necessary to take down the suspension to do this).

III. Find the (minimum) distance between the threads in cm. with the screw gauge. Be careful not to push the threads out of place by the teeth of the gauge.

IV. Find the length of the threads in cm., by the metre rod.

V. Calculate the weight in grams on each thread (assuming it to be equally divided between the two), and reduce this to dynes, by the usual factor (980.0 at Berkeley. See Exps. 1. and 45).

VI. Calculate the deflection of each thread from the vertical. (This is approximately equal to the half distance between the threads multiplied by the sine of the mean angle of deflection).

VII. Calculate the horizontal component of the force of gravity exerted upon each thread (by multiplying the total force in dynes by the ratio of the deflection from the vertical to the total length of the thread).

VIII. Calculate the couple due to the force of gravity.

IX. Knowing, by Exp. 46, the location of the poles, find the horizontal force in dynes on each producing a couple equal to that due to gravity.

X. Knowing, by Exp. 46, the strength of the poles of your magnet, find the (horizontal component of the) force exerted by the earth upon each unit of magnetism which these poles contain. What name is given to this last result? (See Exp. 47.)

XI. Suppose that you had overestimated the strength of your magnetic poles in Exp. 46, by say 100%. What error would this introduce in your estimate of the (horizontal component of the) earth's magnetic field in Exp. 47? in Exp. 48?

XII. Account any large difference between your estimates of the (horizontal component of the) earth's magnetic field in Exps. 47 and 48; and find the geometric mean between these two estimates. Why is this geometric mean unaffected by any error in your original estimate of the strength of the poles of your magnet?

Note. Students who find difficulty in following out the reductions of results obtained with the "bifilar suspension" will do well to ask for special instructions as to the use of a piece of apparatus by which these difficulties may be avoided. The apparatus consists, essentially, of a mechanical device, through which the horizontal force exerted by the earth's magnetism upon the poles of a suspended magnet may be directly counterpoised with weights. The use of a bent lever for this purpose was originally suggested by Professor Slate.

49. THE EARTH'S LINES OF FORCE.

APPARATUS: A sun-dial, with compass attached; a prismatic compass; a dipping-needle.

NOTE. KEEP THE NEEDLES ARRESTED SO AS NOT TO WEAR OUT THEIR POINTS OF SUSPENSION WHEN NOT IN USE.

I. Find the magnetic declination by either of the two following methods:

A. If the sun is shining, use a SUN-DIAL. (1.) Subtract 9 minutes from any anticipated reading of the mean time clock(which gives the mean time of the 120th meridian west of Greenwich), to find the local (Berkeley) time; then subtract the "equation of time" from the nautical almanac, or from table 44 G, for the given day of the year, to find the "apparent" or sun's time, which, owing to the irregular motion of the earth, varies from mean local time by from 0 to 16 minutes at different times of year.

Example: Berkeley, March 8th, 1891, 1.30 P. M.

	H.	MIN.
Expected time of observation	2	0
Subtract to reduce to local time (nearly)........	+ 0	9
Mean local time	1	51
Subtract equation of time for March 8th,(nearly) .	+ 0	11
Apparent (or sun's) time........................	1	40

(2.) Raise the latitude quadrant of the sun-dial.— Then raise the hour-circle until the arrow points to the latitude (37.8 degrees for Berkeley). Turn the shadow-wire at right-angles to the hour-circle, upward in summer, downward in winter so as to cast a shadow upon the hour-circle. Set the instrument out doors upon the nearly horizontal surface of a wooden stool (glued not nailed together), and at a

distance from any building or structure containing iron. Turn the instrument until the shadow indicates approximately the apparent time. Level it by means of the foot-screws. When the expected time arrives, turn the instrument so as to indicate exactly the corresponding apparent time, previously calculated.

The fiducial line of the fixed circle of the compass attached to the sun-dial should now indicate TRUE north and south. The departure of the compass-needle from true north is therefore to be read from the graduated circle of degrees. Note that this is called the "magnetic declination" of the place.

B. If the sun is not shining, use a PRISMATIC COMPASS. This method requires the use of two reference marks, the second of which has a known bearing from the first. These marks are to be indicated by the instructor. Place the instrument at the first reference mark, and make it as nearly level as possible. Be sure that the prism is uncapped, and that the scale is in focus. Turn the instrument until the second reference mark is seen through the slit just above the prism so as to be bisected by the cross-hair. Lower the eye until the cross-hair seems to intersect the scale, and read the scale to find the magnetic azimuth of the line joining the two reference marks. Subtract this from the true azimuth of this line (furnished by the instructor) to find the magnetic declination.

II. Mount the prismatic compass upon a block of wood, with edges parallel to the line of sight, and set it out of doors with the sides of the block parallel to the walls of the building, but as far away from them as practicable. Find the magnetic azimuth of these walls, and deduce their true azimuth.

III. Find the magnetic declination on all the tables in the laboratory by placing the prismatic compass, with the edges of its block parallel to the edges of the tables, previously squared to the walls. Make a map showing the magnetic declination at the several points examined, and

draw contour lines, if possible, showing points of equal magnetic declination.

IV. Place the "dipping-needle" on each of the benches where the magnetic declination has been found, with the plane of its graduated circle parallel to the magnetic meridian, and note the direction of the earth's lines indicated by the needle.*

Make a map showing the "dip" at several points, and draw contour lines, if possible, connecting points of equal dip.

See whether any similarity can be made out between the contour lines in III. and IV., and whether their similarity, if it exists, can be attributed to the presence of large masses of iron, such as a stove, gas-pipe, or a girder used in the construction of the building.

* This method of finding the "dip" at different points is sufficiently accurate for the purpose of drawing contour lines. Accurate results with a dipping-needle require, in general, a reversal of its bearings as well as of its magnetism. The latter process should not be attempted without special instructions.

50. MAPPING MAGNETIC FIELDS.

Apparatus: A pair of magnets tested in Exp. 46; some iron filings; some blue-print paper;* a sheet of common paper; a small compass with controlling magnet; a sheet of cardboard, and some wax.

I. Fasten one of the magnets with wax to the under side of a piece of blue-print paper, a little larger than the magnet; mark in pencil upon the paper the position of the north and south poles; scatter some iron filings over the sensitized surface, and expose to the sunlight until the paper turns blue. Then remove the magnet and the iron filings, and wash the blue-print 5 or 10 minutes in water, so as to fix the image of the iron filings.

II. Repeat I. with two magnets side by side, but about 2 cm. apart, and with similar poles opposite.

III. Repeat II. with one of the magnets reversed. Compare the figures obtained in I., II., and III.

IV. Lay the blue-print obtained in I. on the middle of the sheet of ordinary paper, and over it the magnet used in I., with its poles as nearly as possible in the same relative position.

Place a small compass at different points of the figure, and observe how it points.

How does the direction of the needle compare with that of the lines of iron filings ?

V. Neutralize the earth's action upon your compass-needle as follows: take a sheet of cardboard of sufficient size, and square it with the edges of your table. Fasten your compass with wax to the most northerly or southerly

* For the preparation of blue-print paper, see Exp. 30.

corner of your cardboard, as convenience may suggest. Remove all magnetic material from the neighborhood, and draw in pencil a magnetic meridian passing through your compass. Neutralize the earth's magnetism as in Exp. 47, I. or II., by a controlling magnet properly located. Be sure to keep the sides of the cardboard PARALLEL TO THE EDGES OF THE TABLE in the experiments which follow.

Why is your compass-needle now sensitive to very slight magnetic forces?

VI. Draw a circle, 2 or 3 cm. in diameter, round each of the poles, and divide the circumference into 10 or 12 equal parts. Through each division draw a pencil line parallel at every point to the lines of iron filings on each side of it, as far as these lines can be recognized in the blue-print.

Place your compass-needle, protected as in V. from the influence of the earth's magnetism, at the end of one of these pencil lines, and extend this pencil line an inch or more in the direction indicated by the needle. Prolong all the pencil lines in this way, an inch or so at a time, beyond the limits of the blue-print, as far as the limits of the sheet of ordinary paper beneath it will permit.

Where do the lines lead you? And what correspondence do you observe between the poles of the magnet, as located in Exp. 46, and the regions to or from which the lines of magnetic force converge or diverge?

VII. With the north and south poles, N and S (located in Exp. 46) as centres, draw arcs with radii 3/4 NS and 5/4 NS respectively, and from their point of intersection, P, lay off a distance of 9 cm. in the direction PS, to represent the force exerted by S upon a magnetic north pole at P.

In what direction would this same pole be urged by N? and how long a line must be laid off in this direction to represent the magnitude of this force (remembering the law of inverse squares worked out in a previous experiment)?

Find, by the parallelogram of forces, the resultant of the

two forces on P. How does this compare in direction with the lines of magnetic force in the vicinity of P? and why?

VIII. Make as in I. a print showing the lines of force due to a long thin coil of wire, carrying an electric current. (The ends of the wire are to be connected for this purpose with the poles of a battery. They should remain connected for as short a time as possible, to avoid waste of electric energy).

How do the lines of force due to the coil compare with those due to the magnet in I.?

IX. Repeat VIII. with a thin flat coil. What angular relation exists between the direction of the lines of force and the direction of the wires?

X. Make a print showing the distribution of iron filings due to a current passing through a vertical coil of wire in the shape of a hoop, bisected by the horizontal plane on which the filings are spread.

What is the angular relation between the lines of force near the wires and the portions of wire nearest the iron filings?

What angular relation exists between the lines of force due to the coil, and the lines of force due to a magnet having its poles at the points where the coil cuts the horizontal plane?

51. ELECTROMAGNETIC RELATIONS.

APPARATUS: A jar of acid; a floating rectangle of wire, with terminals consisting of a zinc and a copper plate dipping in the acid; a permanent bar magnet; a compass; and a small dipping-needle.

I. Float the rectangle in the jar of acid so that the electric current, which flows through it (according to convention) from the copper plate to the zinc plate, may follow a northerly course through the upper wire. Hold the comcompass over this wire, and as close to it as possible. Is it deflected at all? and if so, toward the east or the west?

II. Repeat I. with the compass under the wire.

III.—IV. Repeat I. and II. with a southerly current.

V. Find the effect of an ascending current on a compass-needle north of it.

VI. Repeat V. with the compass south of the current.

VII.—VIII. Repeat V. and VI. with a descending current.

NOTE. In Experiments IX.—XXIV., which follow, the rectangle must be kept floating in the middle of the jar, so as to be free to move.

IX. Hold the north pole of your magnet over a wire carrying a northerly current. In what direction is it urged?

X. Repeat IX. with the north pole under the wire.

XI.—XII. Repeat IX.—X. with a southerly current.

XIII. Find the effect of holding the north pole of your magnet close to and on the north side of a wire of the rectangle carrying an ascending current.

XIV. Repeat XIII. with the north pole on the south side of the ascending current.

XV.—XVI. Repeat XIII.—XIV. with a descending current.

XVII.—XXIV. Repeat IX.—XVI. with the south pole of your magnet substituted for the north pole.

XXV. Answer the following questions:

(1). How does the reversal of the direction of the current affect your results?

(2). How does the substitution of a south for a north pole affect results?

(3). How does a change of position in a magnetic pole from one side of a wire to the opposite side affect results?

(4). How does the direction in which a magnetic pole (e. g. either pole of a compass-needle) is urged by a current compare in each case with the direction in which the wire carrying the current is urged by a similar pole?

(5). What peculiarity do you observe in the angular relation between the line joining the (supposed) agents in these electromagnetic phenomena and the direction of the forces brought into play? and what angle do these two directions make with that of the electric current?

(6). Represent the direction of the current in each case under I.—VIII., by the forefinger of your right hand. Place your thumb ACROSS your forefinger, and turn the wrist until the thumb is above, below, north, south, east, or west of the finger, according to whether the compass is above, below, north, south, east, or west of the current. State in each case whether the thumb does or does not represent the direction toward which the north pole of the needle is deflected.

XXVI. Why do horizontal currents have no effect upon a compass-needle on their own level (assuming that the needle is free to move only in a horizontal plane)?

Confirm your answer by the use of a dipping-needle, and state how you do this.

XXVII. Why do easterly or westerly currents have in

general little or no effect upon a compass-needle above or below them?

Confirm your answer by the use of a compass-needle, made to point east and west by means of a controling magnent, as in Exp. 47.

XXVIII. Why do vertical currents have in general little or no effect upon a compass-needle east or west of them? Confirm your answer as in XXVII.

XXIX. Make a diagram showing the path of a magnetic pole, free to move under the influence of a vertical current.

What is the relation of such a path to the so-called lines of force due to the current? (Ask if you do not know).

Why are the lines of force in Exp. 50, X., nearly circular close to the wires?

XXX. In what direction should a rectangle (or coil) of wire deflect a magnetic needle at its centre if the current in the upper side of the rectangle is (1) northward? (2) southward? (3) eastward? (4) westward?

How should a (galvanometer) coil be set up so that the magnetic needle at its centre may be as sensitive as possible to feeble currents through the coil?

Confirm these conclusions by experiment if necessary.

WHEN YOU HAVE FINISHED WORKING WITH THE FLOATING APPARATUS, CLEANSE IT WITH WATER, AND SET IT TO DRY.

52. LAWS OF ELECTROMAGNETIC ATTRACTION.

Apparatus: Materials for three rough tangent-compass galvanometers; a battery and connecting wires.

I. Take a piece of insulated No.·16 wire, about 4 metres long, and bend it into a circular loop about 24 cm. in diameter. Twist the free ends together, enough to keep them from separating. Bind the loop in a clamp, so that its plane may be vertical, and so that a compass may be placed at the centre of the loop. Turn the clamp round so that the plane of the loop is parallel to the magnetic meridian, determined by drawing a pencil line on the table in the direction indicated by the compass-needle.

Place the compass at the centre of the loop, and turn it round so as to read zero. Connect the terminals of the loop with a constant battery. (Ask to have the storage battery connected). Read the deflection of the compass-needle. Then interchange the connections between the battery terminals and the terminals of the loop, and again read the deflection. What effect does this interchange have upon (1) the magnitude and (2) the direction of the deflection?

Always reverse your battery and average the two deflections to find the true deflection caused by the current. Why are errors in the adjustment of the zero eliminated in this way?

II. Repeat I. with two turns of wire instead of one. Also with three, and also with four turns of wire.

How does the tangent of the angle of deflection compare with the number of turns of wire in the coil? with the length of wire in the coil?

Why is the tangent of the angle of deflection proportional to the field of force due to the current? (Ask if you do not know).

III. Repeat I. with two coils of wire having the same total length as the single coil in I.

How does the average distance of the wire from the centre of the compass-needle compare in I. and III.? Assuming that the forces on a magnetic needle due to a current through a given length of wire are proportional inversely to some integral power of the mean distance between the wire and the needle, what is the power in question?

IV. Set up three instruments as in III. as far apart as may be practicable. Connect them with the battery so that the current flows half through No. 1, and half through No. 2, but all through No. 3. Read the deflections of all three instruments.

If the effect of a current upon a magnet is proportional to some integral power of the current, what is the power in question ?

Express the field of force, F, at the centre of a coil of wire, as proportional directly or inversely to some power of the three following quantities: (1) The current, C; (2) the length of wire in the coil, L; and (3) the radius of the coil, R.

53. TESTING AN AMMETER.

Apparatus: A source of electricity; a tangent galvanometer; a metre rod with calipers; an ammeter, and some German silver wire.

I. Set up the ammeter and the tangent galvanometer at opposite corners of the table, so as to free them in so far as possible from mutual action; and adjust both instruments so as to read zero. Pass a current in series through the two instruments. Twist the terminals of the tangent galvanometer together, so that the equal and opposite currents in these terminals may neutralize each other in their effect upon the galvanometer. Do the same with the terminals of the ammeter, and with the battery terminals. Note that the double cords, thus formed, resemble the letter T in shape, the battery, galvanometer and ammeter being situated at the extremities of the T.

Make simultaneous readings of both ends of both needles, (one in the tangent galvanometer, the other in the ammeter).

II. Repeat I. with the terminals of the ammeter interchanged, so as to reverse the current in the ammeter.

III. Repeat II. with the terminals of the galvanometer interchanged, so as to reverse the current in the galvanometer as well as in the ammeter.

IV. Repeat III. with the terminals of the ammeter as in I., so that the current may be reversed in the galvanometer, but not in the ammeter, as compared with I.

Note that the arrangements in I.—IV. represent every possible combination of directions of the current through the two instruments.

Why is any error in the zero of either instrument eliminated in taking the average of the four readings in I.—IV.?

Why is the mutual action of the two instruments eliminated by the same method? Would this mutual action be eliminated by simply reversing the current through both instruments?

V. Repeat I.—IV. with about 50 cm. of No. 25 German silver wire included in the circuit. Why is the current less than before?

VI. Repeat I.—IV. with two coils of German silver wire in the circuit.

VII. Repeat I.—IV. with the two coils as in V. but in parallel, not in series, so that half the current may flow through each.

Under what circumstances do two coils of wire diminish the current from a given source more, and under what circumstances less, than a single coil?

VIII. Find the length of wire in the galvanometer coil; also find the mean radius of this coil. Given that the "C. G. S." unit of current is such as to produce a unit field of force in a coil of unit length and unit radius, also that the earth's field on your table is 0.24 dynes per unit of magnetism, how can you calculate the current through the tangent galvanometer in I.—IV.? in V.? in VI.? and in VII.?

Suggestions: The strength of earth's field (0.24) is known. (Look up your own determinations in Exps. 47 and 48.)

The tangent of the angle of deflection gives the ratio between the current's field, and the earth's field, because these are at right-angles. Hence the current's field can be calculated.

The relation between the current strength, the length of wire in a coil, the mean radius of the coil, and the current's field has been worked out in the form of a proportion in a previous experiment.

You are now told to substitute equality for proportionality, this being the result of the definition of the C. G. S. unit of current.

In the equation thus obtained, all the quantities are known except the current, hence the current can be calculated.

IX. Given that the units indicated by the ammeter are some decimal multiple or submultiple of C. G. S. units, what is the multiple or submultiple in question?

54. HEAT AND RESISTANCE.

APPARATUS: A source of electricity, two coils of No. 25 German silver wire, about 50 cm. each; an ammeter; a calorimeter, and a thermometer; access to a clock, and to scales with weights.

NOTE. The electrical resistance of a conductor depends upon the power necessary to maintain a given current through it. The power is invariably transformed into heat, and the object of this experiment is to measure it by means of its heat equivalent. The unit of power adopted in practical use is the "watt," or 10,000,000 dynes with a working velocity of 1 cm. per sec. The relation between the heat unit and the watt can be made out from your own observations as follows:

1 unit of heat per sec. = about 30 gram-degrees of lead shot per sec. (Exp. 19).

1 gram-degree of lead shot per sec. = about 1420 gram-cm. of work per sec. (Exp. 21).

1 gram-cm. of work per sec. = about 980 dyne-cm. of work per sec. (Exp. 45).

1 dyne-cm. of work per sec. = .000,000,1 watt (by definition).

Therefore 1 unit of heat per sec. = about

$$30 \times 1420 \times 980 \times .000,000,1 = 4.17 \text{ watts.}$$

I. Weigh the inner cup of the calorimeter, and place in it about 50 grams of water, at a temperature some 5 degrees below that of the room; pass an electric current in series through the ammeter (previously adjusted so as to read zero) and through one of the coils of German silver wire. Immerse this coil in the water of the calorimeter. Note the temperature every minute for about 10 minutes, stirring continuously between observations. Note also the corresponding readings of the ammeter.

What is the effect of passing a current through the conductor upon the temperature of this conductor and the water in contact with it?

II. Repeat I. with the second coil of wire also included in the circuit, but not immersed in the calorimeter.

What is the effect of interposing this additional length of wire (1) upon the magnitude of the current? and (2) upon the amount of heat generated in a given time?

Assuming that the amount of heat generated in a given conductor in a given time is proportional to some integral power of the current as measured by the ammeter, what is the power in question?

III. Repeat II. with both coils immersed in the water. How does the heating of a conductor by a given current compare with the length of wire traversed by that current?

IV. Repeat III. with the two coils arranged so that half of the current traverses each.

What is the effect upon the magnitude of the current, due to paralleling a conductor with another conductor?—(Compare Exp. 53, VII.)

V. Calculate in each case (I.—IV.) the water equivalent of the calorimeter and its contents (by adding 2 grams to the weight of water which it contains), then the No. of heat units (gram-degrees) developed in one second, then the equivalent power in watts (see introductory note). Divide the power in watts by that power of the current to which you judge the heating effects to be proportional. Note that this quotient is called the resistance of the conductor in question, and that it is given in "ohms."

How does the resistance in ohms of a given conductor compare in I. and II.? How does the resistance of a given conductor compare with that of two similar conductors in series? in parallel?

55. DIVIDED CIRCUITS.

Apparatus: A constant battery, an ammeter, a micrometer, and a rheostat.

I. Find the diameter of the rheostat wires with a micrometer. Pass the current from the battery through the ammeter, then through 80 cm. of the large wire of the rheostat. This is done by means of a sliding clamp, fixed at 80 cm. from one of the binding screws. Note the deflection of the ammeter.

II. Substitute for 80 cm. of the large wire, such a length of the first small wire as may be necessary to reduce the deflection of the ammeter to the same amount as before. Note the length of the wire in question.

III. Pass the current through two small wires in parallel, making the lengths equal, and find what length will give the same current as before.

IV. Repeat III. with three small wires in parallel.

V. Repeat III. with four small wires in parallel.

VI. Repeat V. with the same lengths of wire in series instead of in parallel, and note the deflection of the ammeter.

VII. Pass the current through the ammeter and then through the whole length of the large wire with one of the small wires in parallel, and note the deflection of the ammeter.

VIII. With the connections as in VII., in other respects, take the ammeter out of the main circuit, and insert it in the branch circuit containing the larger wire of the rheostat.

IX. Transfer the ammeter to the branch circuit containing the smaller wire of the rheostat.

X. Answer the following questions:

1. How do the resistances of the rheostat in I., II., III., IV., and V compare and why? (Ask if you do not know).

2. Does a large or a small wire of given length offer the greater resistance to an electric current? (Assume that the resistance of a wire is proportional to its length, other things being equal, and that, consequently, if a smaller length of one wire is equivalent to a greater length of another, the former has the greater resistance for a given length.

3. How does the resistance of a given length of a double, treble, or quadruple wire of a given sort compare with that of a single wire?

4. How does the resistance of a given length of a large wire compare with that of an equal length of several small wires of the same material, in parallel, when the total cross-section of the small wires is equal to that of the large wire? (Bear in mind that the cross-section varies as the square of the diameter).

5. If the resistances of equal lengths of a wire of given material are proportional to some integral power of the cross-section (directly or inversely), what is the proportionality in question?

6. Is the resistance of several wires in parallel the same as in series? What evidence have you on this point from this experiment?

7. Is the resistance of a large wire increased or diminished by the addition of a small wire of the same length in parallel?

8. Does the greater portion of the current in a divided circuit flow through the channel of greater or less resistance in your experiments?

9. Assuming that the portions of a current in a divided circuit are proportional to some power, direct or inverse, of the resistances of their respective channels, what is the proportion in question?

56. ELECTRICAL EFFICIENCY.

APPARATUS: Two beakers of about 100 grams capacity; a small zinc-carbon pair to fit into either beaker; a resistance-coil (about 1 ohm, acid proof); some bichromate battery solution; a thermometer; a balance with weights to 1 decigram, and access to a minute clock.

I. Make a mark on both beakers corresponding to a capacity of 100 cu. cm.; weigh the zinc-carbon pair, place it in one of the beakers, and fill this beaker with bichromate solution until it comes up to the 100 cu. cm. mark WITH THE BATTERY IN PLACE.

Connect the two terminals of the resistance-coil with the screw-cups of the battery, and immerse the coil in the bichromate solution beside the plates of the battery. Note the temperature every minute until it has risen 10 degrees, stirring the liquid all the time by moving the plates of the battery. Reweigh the zinc-carbon pair.

II. Repeat the experiment with the zinc-carbon pair in the second beaker, filled up to the 100 cu. cm. mark as before; but place the resistance coil in the first beaker, containing the exhausted battery solution, cooled to its original temperature by ice, or otherwise, and filled up so as to occupy 100 cu. cm. as before. In the repetition of this experiment, note every minute the temperature not only of the battery, but also that of the beaker containing the resistance-coil, and stop the experiment when the current has run about the same time as in I.

NOTE. The object of having 100 cu. cm. always in the beakers is that the thermal capacity may be as nearly as possible the same. The thermal capacity of the zinc-carbon

pair is not very far from that of an EQUAL BULK of battery solution.

Answer the following questions:

1. Calling the thermal capacity of each beaker with its contents 100 units, find the No. of heat units developed by the battery in I.

2. Assuming that the carbon pole of the battery is unacted upon, how much zinc has gone into solution?

3. If the heat developed is due to the solution of the zinc, how many units of heat would one gram of zinc account for?

4. Find the number of heat units developed by the solution of one gram of zinc (a) in the battery in II. and (b) in the beaker containing the resistance-coil in II. Why is the result in 4 (a) less than in 3?

5. How does the total number of heat units developed by one gram of zinc in II. compare with that in I.? and why?

6. Find the proportion of chemical energy of the battery transmitted to the resistance-coil. What name is given to such a proportion? (Ask if you do not know.)

57. ELECTROCHEMICAL RELATIONS.

APPARATUS: Two Daniell cells, three vessels filled with sulphate of copper solution, six copper plates, and an ammeter. Access to scales with weights to 1 decigram. A jar of water.

I. Weigh each of the six copper plates, also the two copper poles of the Daniell cells. In each of the vessels containing sulphate of copper, immerse a pair of copper plates, so that a current cannot pass from one of a given pair to the other without traversing the liquid. Note that the three instruments thus formed are called copper voltameters.

Connect the Daniell cells in series, and let the current pass in series through the ammeter and through one of the copper voltameters. Then let the current divide so that one part passes through the second voltameter and the other part through the third voltameter. The whole current, uniting again, must return to the battery.

Let the current run for 50.8 minutes. Note the deflection of the ammeter every minute during this time. Then wash, dry and reweigh the six copper plates and the poles of the Daniell cells.

Answer the following questions:

(1) Have the poles of the Daniell cells gained or lost in weight? and by an equal or by an unequal amount?

(2) Which of the voltameter plates have gained, and which have lost in weight? State whether the current from the copper pole of the Daniell battery entered the liquid by the plate or left liquid by the plate in each case.

(3) Is copper carried with or against the current?

(4) How do the changes of weight of two plates of a given voltameter compare in sign and in magnitude?

(5) How does the change in weight of the poles of the Daniell cells compare with that of the voltameter plates transmitting the whole current?

(6) How do the changes of weight in the plates of a voltameter transmitting the whole current compare with those of the voltameters transmitting each a fraction of the current?

(7) If the amount of copper deposited on one of the plates of a voltameter is proportional to some integral power of the current, what is the power in question?

(8) How does the weight of copper deposited by a current in 50.8 minutes compare with the current in ampères, as indicated by the ammeter?

58. ARRANGEMENT OF BATTERIES.

APPARATUS: Two Daniell cells; 1 Bunsen cell; an ammeter; a resistance-coil, and connecting wires.

I. Connect one of the Daniell cells with the ammeter and resistance-coil in parallel. Note the deflection.

Disconnect the terminals of the resistance-coil so that the whole current flows through the ammeter. Is the reading of the ammeter greatly affected by this change? How do you explain this fact?

II. Connect the resistance-coil and ammeter with the Daniell cell in series, and note the deflection; then shunt out the resistance-coil with a short, thick copper wire. Is the reading of the ammeter greatly affected? and why?

From your results in I. and II. give some idea of the relative resistances of the ammeter and the resistance-coil, the ammeter and the battery, also the resistance-coil and the battery, assuming that the resistances are, other things being equal, inversely as the currents which traverse them.

III. Find the reading of the ammeter when connected with

(a) a single Daniell cell.
(b) the other Daniell cell,
(c) the two Daniell cells in series,
(d) the two Daniell cells in parallel,
(e) the Bunsen cell,
(f) the Bunsen cell and the two Daniell cells in series.

How should cells be connected (in series or in parallel) to give a maximum current through a galvanometer of low resistance?

IV. Repeat III. (a)—(f) with the resistance-coil in series with the ammeter.

How should cells be connected so as to give a maximum current through a high resistance?

Would you prefer a galvanometer of high or low resistance to appreciate effects due to combining cells in parallel?

Should the resistance of a galvanometer be high or low if the instrument is to be used in estimating effects due to combining cells in series.

Note that such a galvanometer is called a voltmeter.

59. ELECTROMOTIVE FORCE.

Apparatus: A Bunsen cell, 3 Daniell cells, two Leclanché cells, and a voltmeter.

I. Connect the voltmeter with two of the Daniell cells in series, but joined copper to copper, (or zinc to zinc) so that their "electromotive forces" are opposed to each other. Are the two electromotive forces unequal or (nearly) equal? Give reasons for your answer.

II. Repeat I. with a different pair of Daniell cells.

III. Repeat I. with the third possible pair of Daniell cells. What reason have you for thinking that all three cells are approximately equal in electromotive force?

IV. Repeat I. with two cells in series connected copper to zinc, so that their electromotive forces may act in the same direction.

V. Repeat IV. with the three Daniell cells in series, connected copper to zinc in each case.

How does the readings of the voltmeter compare with the joint electromotive force in the circuit in I.—V.?

VI. Repeat V. with one of the cells reversed, so as to act in opposition to the other two.

What is the effective electromotive force in this case, and how does it compare with the reading of the voltmeter?

VII. Assuming now that the voltmeter will measure correctly the electromotive force in every case, find the electromotive force of each Leclanché cell, and of two Leclanché cells in series, also the electromotive force of the Bunsen cell.

VIII. Oppose the Bunsen cell in series against as many Daniell cells as should give about the same electromotive force, and find the effect of the combination on the voltmeter.

IX. Oppose as many Leclanché cells as may be equal in electromotive force to a given number of Daniell cells against the number of Daniell cells in question, and find the effect upon the voltmeter.

What in general do you conclude to be the effect of opposing batteries with equal electromotive forces?

X. Join two Daniell cells in parallel, and oppose them to a single cell in series with the voltmeter.

How does the electromotive force of two cells in parallel compare with that of a single cell of the same kind?

XI. Test your conclusion in X. by actual measurement with the voltmeter, upon one, two, and three Daniell cells in parallel.

What in general is the effect of joining cells (of a given kind) in parallel upon their joint electromotive force?

XII. Find the electromotive force of three Daniell cells in series with the two Leclanché cells and the Bunsen cell.

What in general is the effect of joining cells in series upon their joint electromotive force?

60. OHM'S LAW.

APPARATUS: Two Daniell cells; 1 Bunsen cell; an ammeter; a voltmeter; a rheostat.

I. Measure off lengths of German silver wire, the same size as that used in Exp. 54, sufficient to give resistances of 1, 2, 5, and 10 ohms. (Consult results of Exps. 54, and 55). Send a current from 1 Daniell cell through each of the resistances in turn, and note the deflection, in each case, of an ammeter included in the circuit, in series with the resistance in question. Also note the indication of a voltmeter connecting the poles of the cell.

II. Repeat I. with two Daniell cells in series.

III. Repeat I. with two Daniell cells in parallel.

IV. Repeat I. with the Bunsen cell instead of the Daniell.

V. Repeat I. with the Bunsen and two Daniell cells in series.

VI. Make a table showing in the first column, the currents in ampères, in the second column, the resistances in ohms corresponding to these currents, and in the third column, the corresponding readings of the voltmeter. Calculate a fourth column showing the product in each case of the current and resistance.

How do the products of current and resistance compare with the indications of the voltmeter?

Given that the product of the resistance of a conductor in ohms and the current in ampères which traverses it is equal to the difference of potential or "electromotive force" in volts between its terminals, what is the value in volts of the divisions of the voltmeter? (Assume that these divisions represent some simple multiple or submultiple of a volt).

Find a simple law expressing the current in terms of resistance and electromotive force (OHM'S LAW).

VII. Find as in Exp. 59 the electromotive force of each combination of cells mentioned in I.—V., also find, as in Exp. 58, the current sent by each through the ammeter with connecting wire of practically no resistance. Calculate by Ohm's law the resistance of each combination of cells.

How does the resistance of a battery consisting of two cells in parallel compare with that of a single cell?

How does the resistance of two cells in series compare with that of a single cell?

Calculate by Ohm's law the electromotive force of the cells in I. and II., remembering to add the battery resistance to that of the rheostat. Is this electromotive force constant?

61. FALL OF POTENTIAL ALONG A CONDUCTOR.

APPARATUS: Two or more batteries; an ammeter; a voltmeter; and a rheostat.

I. Pass a current in series through the ammeter and the rheostat. Find by the voltmeter the difference of potential at the extremities of one of the rheostat wires having a resistance of one ohm.

Repeat with different wires having also resistances of one ohm.

How do the readings of the voltmeter compare with one another.

How do the readings of the voltmeter compare with those of the ammeter and why?

II. Connect one terminal of the voltmeter with one of the battery poles, and connect the other end with different points on the rheostat. Note the reading of the voltmeter in each case.

How do the readings of the voltmeter compare with the resistances in the main circuit between the points of contact?

III. Repeat II. with the fixed terminal of the voltmeter connected with the other pole of the battery.

IV. Repeat II. or III. with a stronger battery.

How does the fall of potential between two points compare with the current?

V. Make as in Exp. 60 a table showing the relation between the readings of the voltmeter and the products of the current and resistance between its poles.

Does Ohm's law apply to portions of a circuit as well as to the circuit as a whole?

VI. Pass a current through the ammeter and an unknown resistance in series. Find the difference of potential between the two terminals of this unknown resistance.

Calculate the resistance in question by principles already worked out.

VII. Draw one or more curves showing the fall of potential between the two poles of a battery. Lay off resistances as abscissas, and differences of potential as ordinates. Mark each curve with a number representing the current in ampères.

62. ELECTRICAL POWER.

Apparatus: A source of electricity; an electric motor; a transmission dynamometer, and a friction brake. A voltmeter and an ammeter.

I. Send a current through the motor and through the ammeter in series. Connect the terminals of the motor through the voltmeter as a shunt. Read both instruments. Multiply the current in ampères by the electromotive force in volts to find the electrical power in watts spent upon the motor. (Ask why if you do not know).

Find the tension in dynes (1 gram weight equals 980 dynes at Berkeley) on each cord of the transmission dynamometer, remembering that twice this tension is felt by the spring balances, and find by subtraction the difference in tension between the two cords leading to and from the pulley of the motor. Find the total length of the cord, and the time of one complete journey around the pulleys, by means of the appropriate observations. Calculate the velocity of the cord in centimetres per second.

Find the power in watts transmitted through the dynamometer by multiplying together the velocity of the cord in centimetres per second and the difference of tension in dynes, and pointing off seven places of decimals. (See Exp. 54, introductory note.)

Find the ratio of the power utilized (through the transmission dynamometer) to the power spent by the source of electricity on the motor. What name is given to this ratio? (Ask if you do not know).

II. Repeat I. with different amounts of friction upon the machinery set in motion through the transmission dynamometer. Find (1) the maximum power of the motor with the given source of electricity, and (2) the maximum efficiency of the motor under the conditions of the experiment.

63. MAGNETO-ELECTRIC INDUCTION.

APPARATUS: A ballistic galvanometer; 2 coils of wire, with magnetized steel and soft iron cores; a wire to shunt the galvanometer, and a battery.

I. Make sure that your galvanometer is free to swing, and find (1) which of the rods is the steel magnet, and (2) which end of this rod is the north pole, by its action on the galvanometer needle.

Connect the two terminals of the galvanometer with the shunt provided for this purpose, so that it will not be too sensitive, and find, by connecting the galvanometer with the battery, which terminal of the galvanometer should be joined to the positive (carbon or copper) pole in order that the deflection may be right-handed.

Remove the shunt and see that the galvanometer is once more in working order. Connect it with the terminals of the smaller coil. Insert the north pole of the magnet into this coil, and note the behavior of the galvanometer. If it moves at all, state whether the motion is sudden, or gradual, and whether the deflection is permanent or temporary.

II. When the galvanometer needle has come to rest, suddenly withdraw the magnet. Note the deflection of the galvanometer.

Is the direction of the deflection the same in II. as in I.? In what direction does the induced current circulate in the coil, as seen from a point outside, looking toward the north pole, in I. and in II.?

III. Repeat I. and II. with the south pole for the north pole.

IV. Repeat I. with the soft iron instead of the steel.

V. With the soft iron still within the coil, find the effect of touching one end of the soft iron with the magnet. How does this compare with the effect of introducing the same pole within the same opening of the coil?

VI. Find as in V. the effect of breaking connection between the soft iron and the magnet.

VII. Place the magnet within the coil, and find the effect of touching the soft iron to one end of it. Can this be accounted for by supposing the magnetic pole to spread along the iron?

VIII. Find the effect of breaking connection between the magnet and the iron, and compare the result with that in VII.

IX. Connect the larger coil with the galvanometer, place the smaller coil within it, and find the effect of connecting the terminals of the smaller coil (when within the larger coil) with the battery. Is the induced current in the same direction as that of the inner coil?

X. Find as in IX. the effect of breaking the primary current, and compare results in IX. and X.

XI. Find the effect of introducing and the effect of withdrawing the primary coil while the current is flowing through it, and compare results with those due to making and breaking the current in the coil without removing it.

XII. Repeat X. with a soft iron core in the inner coil. How are the effects modified by the core (1) in sign and (2) in magnitude?

64. EARTH-INDUCTOR.

APPARATUS: A Delezenne's circle; a ballistic galvanometer.

I. Set the Delezenne's circle at one corner of your table, and the ballistic galvanometer at the opposite corner. Turn the base of the circle so that the brass plate, graduated to 5 degrees, may lie in a vertical north and south plane. Make the axis of revolution horizontal. Connect the terminals of the circle with the galvanometer. Make sure that the galvanometer is free to move. (It is so, probably, if it responds to the approach of your knife, or other steel object).

Turn the coil slowly into a horizontal position. Then turn it suddenly into a vertical plane. Note the action of the galvanometer. How do you account for this?

II. Turn the coil suddenly into a horizontal position, continuing the direction of rotation in I. Compare effects, and explain the result.

III. Turn the coil in the same direction of rotation as in I. and II., through another right-angle. How does the effect upon the galvanometer in III. compare with that in I. and why? (Examine carefully the construction of the "commutator" on the axis of rotation before answering this question).

IV. Turn the coil still farther, back into its original position, and note the effect.

V. Find the effect of continuous rotation of the coil to the right. What would this effect be if there were no commutator?

VI. Find the effect of reversing the direction of rotation of the coil.

VII. Set the circle so as to revolve about a vertical axis, with the brass graduated plate (as in I. and VI.) in a north and south plane. Find the effect of continuous rotation as before.

VIII. Turn the base of the instrument through a right-angle, and again find the effect of continuous rotation.

Explain if you can the effect of turning the base of the instrument through 90°. (If you cannot, ask for help).

IX. Assuming that the effects (as measured by the galvanometer) in V. and in VII. are to each other as the vertical and horizontal components of the earth's magnetism, what is the tangent of the dip? and what (see table of tangents) is the dip of the earth's magnetism?

Turn the base of the instrument back to its original position in I.—VI., and clamp the circle by a series of trials at such an angle that continuous rotation fails to affect the galvanometer. What angle have you found in this way?

65. STUDY OF A MOTOR AND DYNAMO-MACHINE.

Apparatus: An electric motor (convertible into a dynamo); a source of electricity, a voltmeter, an ammeter.

I. Pass a current in series through the ammeter and the motor, held fast so as not to move. Connect the terminals through the voltmeter as a shunt. Calculate the resistance of the motor by Ohm's law.

II. Find as in I. the resistance of the field magnet coils.

III. Find as in I. the resistance of the armature coils.

IV. Repeat I. II. and III. with the armature in motion. Is the resistance of the armature apparently greater or less than before? How is this with the field magnets? Explain these phenomena by the supposition that the resistances are really constant, and that the electromotive force varies.

Under what circumstances can Ohm's law be applied to the parts of an electric motor?

V. Find the effect of forcibly reversing the motor while traversed by the current, with the connections as in III.

What is the effect of doing work upon a current upon its magnitude and electromotive force?

What is the effect upon a current of allowing it to do work against outside forces?

Must work be done upon or by a current in order that the current may be strengthened?

VI. Disconnect the voltmeter, but leave the ammeter in the main circuit, NEXT TO THE ARMATURE of the motor. Start the motor by means of the current.

Force the needle of the ammeter back to zero by a small block touching it only on one side, so as to leave it free to respond to a current in the OPPOSITE direction. Then sud-

denly shunt out the ammeter and the armature by a short thick wire.

What evidence have you that the current induced in the armature by the motion of its wires through the magnetic field of the fixed or "field" magnets is opposite in direction to that by which the motion in question is produced?

Is the armature accelerated or retarded by joining its terminals together, and why?

Note that this experiment affords an excellent illustration of LENZ'S LAW.

VII. For this experiment, the connections may be left as in VI., or still better, the armature and ammeter may be formed into a separate circuit, leaving the field magnets alone in the main circuit with the source of electricity.

Find the magnitude of the current induced in the armature when forced by mechanical means to rotate as rapidly as possible first in one, then in the opposite direction.

Are these induced currents in the same or in opposite directions?

Which way must the armature be made to revolve in order that the induced current may strengthen the main current?

Give some idea of the rate of revolution necessary to produce a current sufficient to maintain the field magnets.

How would you convert your motor into a dynamo-machine?